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Surplus foundry sand and its assessment of applicability in composting

Master of Science in Technology

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Abstract

The purpose of this thesis was to carry out a research on reuse possibility of surplus foundry sand in composting and develop a general proposal for guideline only as appendix in this thesis for the Finnish foundries to assist them in setting quality control system criteria to control the quality of surplus foundry sand suitable for composting and preventing any harm or risk to environment, human and natural resources. The research was made on the typical foundry sand used such as alkaline phenolic sand, furan sand and green sand that are used in Finnish foundries.

The reuse possibility of surplus foundry sand was studied using various articles, journal published in this topic and also based on the experiment conducted by LIFE13 ENV/FI/285 “Foundry sand” project. The proposal to improve the waste quality of surplus foundry sand was prepared under environmental relevant industrial waste management activity (646/2011).

Following conclusion can be drawn from the experiment conducted in three different Finnish foundries’ sand to find its reuse possibility in composting: the composting experiment showed that surplus foundry sand that would have been dumped in landfill contains fluoride, phenol and BTEX. These harmful components disappear during composting. This shows that reuse of surplus foundry sand does not adversely affect the environment.

The proposal prepared for Finnish foundries in this thesis could be a reliable way to get clear and existing advice for them that would ensure and develop confidence about the consistency in quality of surplus foundry sand produced in foundries. It was found that there is a huge scope of applications for using surplus foundry sand.

Keywords **Surplus foundry sand, foundry, re-use, landfills, waste, environment, quality control**

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- Devendra Maharjan

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1. Introduction

1.1 Background

Foundry uses sands to create moulds and cores for metal casting, in which the virgin sands are mixed with variety of inorganic and organic binding agents such as clay or organic chemical binders or resin (Owens, 2008). From mixture moulds are prepared and cores are added if needed. The molten metal at temperature above 1000 ^{0}C is exposed to moulds while casting (Winkler et al. 2000). The molten metal is poured in the mould, and mould is broken down from the casting after casting has been hardened and cooled. In the system new sand is periodically added to maintain optimum moulding characteristics. The excess sand that is generated during casting and dumped in landfills are surplus foundry sand (Lindsay et al. 2005). The sand cores are necessary to create openings in casting. While preparing the core different organic binders are used (Lindsay et al. 2005). The typically used chemical binders are phenolic urethane resin, furfuryl resin, sodium silicate etc. Various catalysts and materials are used for gaining better surface quality of casting and core. Due to the exposure of these binders and additives to higher temperature, majority of these will burn down. The mould and core sands are reused in the foundry multiple times until they wear out due to the mechanical abrasion during moulding process, which are then thrown in the landfills. These discarded sands are called surplus foundry sand or waste foundry sand or spent foundry sand (Dungan et al.2006). Apart from this, many moulds and cores rejected during quality inspection test and discarded in landfills are also surplus foundry sands. Those surplus foundry sands that are not exposed to the high temperature can have wide variety of organic and inorganic chemicals. Boyle et al. (1978) stated that higher organic binder level in the surplus foundry sand is due to the higher percentage of cores used and the type of metal casted.

While contaminants such as large metals and inorganic material in surplus foundry sand (SFS) can be removed by using screening or magnetic separators, the organic contaminants that are the major component of the binder might retain within the sand to various degrees depending upon the foundry process. For example, surplus foundry sand obtained from aluminium casting is likely to result with higher concentrations of organic residues due to low temperature casting process. The organic residue such as phenolic, PAHs, isocyanates, and other organic compound that could retain in SFS depend on the foundry and their process (Ji et al. 2001).

Foundry industry in Europe is third largest for ferrous casting and second largest for non-ferrous casting in the world. In Europe, approximately 18 million tons of surplus foundry sand are produced annually by foundries (LIFE13 ENV/FI/285 "Foundry sand" 2014). Of this sand, extremely less amount are used in construction of road, asphalt production, mineral wool production, concrete production etc. Uncertainties concerning the potential contaminants in surplus foundry sand are the main limiting factor in reusing it (Hindman et al. 2008). Since less research has been done related to the utilization of surplus foundry sand in agriculture and horticulture, there is no specific regulation formed that would motivate SFS reuse in agricultural sector. The huge amount of sands being dumped in the landfills is inviting numerous problems such as necessity of large landfills, increase in dumping cost of surplus foundry sand and excessive use of sand resources. In Finland, there are about 20-30 sites with soil contamination. Landfills are also contributing factors for soil contamination. According to VTT (2000), nearly 0.7 million m^3 of heavily contaminated soil and approx. 10 million m^3 of contaminated soil have to be treated by year 2010. The techniques and regulations need to be developed that would decrease the tedious paper work, motivate the foundries to improve the quality of the surplus foundry sand and increase the end users' and authorities confidence to use surplus foundry sand. This document presents literature review regarding the suitability of surplus foundry sand in agriculture sector and particularly for composting. The document also presents a proposal that would assist foundries in setting specific criteria in order to control the quality of surplus foundry sand. This document also discusses negative effects of reusing surplus foundry sand in environment and creatures.

1.2 Objective of the research

In Finland, only in total about 70 million tonnes of natural mineral are used each year. The virgin materials are decreasing, the need to protect the resource and lengthened travel distance to extract materials have increased necessity to find alternative materials. While industries are producing waste, it has to be realized that they can be used as alternative materials.

The capacity to receive the waste sand from foundry by the landfill sites are limited. The amount of the waste produced is huge. This forces countries to make large 'EU landfills' and to close the small ones. The dumping cost of surplus foundry sand is getting higher due to longer distances, transportation cost and the increasing tipping fee costs. And therefore the number of the foundries declined in Europe and contributed to increasing unemployment rate.

The moulding sand are being used in geotechnical applications such as asphalt and flowable fill, structure fills, construction of road bases etc. The metals accumulated in the moulding sands during casting operations are a threat to the living environment (Dungan, et al. 2008). There are many questions regarding the safety of terrestrial and aquatic life, soil quality and environmental effect. Because of limited research findings regarding the uses of surplus foundry sand, farmers are not confident enough to use it as compost. This limited the wide scope utilization of surplus foundry sand. In addition to this, there is no standard set and no proper regulation made for the utilization of the surplus foundry sand.

In the following section, a review of available literature regarding the reuse of the surplus foundry sand for composting, agriculture use and other purposes is presented. The review aims to achieve following goals:

- Determine whether the surplus foundry sand toxicity level (i.e. phenols, PAHs) is less than the standard.
- Prepare a general proposal that will help to create guideline for foundries to develop quality control system for surplus foundry sand.
- Verify the compost quality and applicability in various agriculture works meeting the national standard for such material.

The motive of this research is however, not to determine standards but to present an overview of existing common factors from which successful standards can be developed. The surplus foundry sand is not uniform and issues of contaminants may be experienced structurally. The structural variation is due to differences in procedures, foundry processes and material used. Uncontrolled use of surplus foundry sand in construction and agriculture work could be harmful to human, living organisms, soil and water resources. Therefore, foundries all over the world felt necessity of proper regulatory guideline for proper disposal of surplus foundry sand for other reuse processes.

This thesis considers almost all kinds of risks possessed by surplus foundry sand to environment, compares them with the standards and prepares general proposal that will help to create guideline. This will motivate foundries to follow it, which in-turn, brings confidence in farmers to use the surplus foundry sand.

1.3 Summary of the key findings

The literature reviewed for this thesis shows several key findings related to beneficial reuse of surplus foundry sand in composting.

- Surplus foundry sand is a high volume industrial waste that can be reused in composting and substitute to landfill disposal: foundries generate sufficient volume of surplus sand that is non-hazardous and consistent in composition; surplus foundry sand exhibits good physical properties (i.e. nutrients contents) necessary for composting; and the landfill capacity is utilized properly since reusable material won't be dumped. (U.S. EPA 2002)
- The land area occupied by landfills is considerable: many countries are working on promotional activities to encourage the greater re-use of construction, industrial and demolition materials. The success of this kind of initiatives has decreased the rate of empty space that could be potentially used for landfills. (Hogg et al. 2002)
- Simple, straightforward regulations that simplify the process for approving reuse in composting can enhance opportunities for safe use of surplus foundry sand. (U.S. EPA, 2014)
- Sustainable production and cost saving are the primary motivating factors for reuse of foundry sand in composting: compost manufacturers get surplus foundry sand in cheaper price compared to virgin sand thus, decreasing their dependency on virgin sand; on the other hand, foundries save transportation cost and tipping fees.
- Promoting the usage of surplus foundry sand among foundries and compost producers can substantially increase the volume of surplus foundry sand for composting.
- Due to high heavy metal concentration in surplus foundry sand from brass foundries, they are not suitable for land applications (Dungan et al. 2006).

1.4. Overview of foundry industry and surplus sand reuse

1.4.1 Foundry sand use within foundries

There are numerous ways in which sand moulds and cores are produced in foundries. The variety of materials used for casting and research of new material or alloys increase challenges to foundry for preparing high technology moulds and cores. Due to the unplanned industrialization in 19th century, we suffered from environmental pollution and threat of natural resources depletion. The dumping of SFS in landfills is becoming expensive and is likely to become more difficult due to stricter government regulations. Because of the recent changes in government policies and the world moving towards sustainability, foundry mould and core preparing technology must meet high environmental protection regulations. Finally, reuse of surplus foundry sand in composting is also cost-effective alternative that might generate revenue to the foundry (Major-Gabrys, 2015).

Foundries reshape the ferrous and non-ferrous metals and alloys in molten metal form pouring and solidifying into mould to get near net shape products. The foundries can generate different types of wastes that include surplus sand from mould and core, unused and broken cores, core sand waste, core room sweepings, cupola slag, scrubber sludge, baghouse dust, shotblast fines and etc., (U.S. EPA, 2015). However, in this thesis, we consider the use of surplus sand obtained only from mould and core.

The total area of Finland is 336,920 km^2. About 60% of the total area is covered by forests and 10% is covered by water (i.e. lakes and rivers). The population of Finland is about 5.3 million of which approximately, one-third lives in coastal regions. Almost all the Finnish foundries are located in the southern and western parts of the country as shown in Figure 1. In Finland, there are limited numbers of sand ores suitable for moulding. There are no naturally bonded sands; the only big and useful quartz deposit is situated in Viasvesi mentioned in Figure 1 near Pori (Autere, 1976). Most of the sand, i.e., chromite sand, required for foundry industry are imported from foreign countries such as Belgium, South Africa (Orkas, 2001).

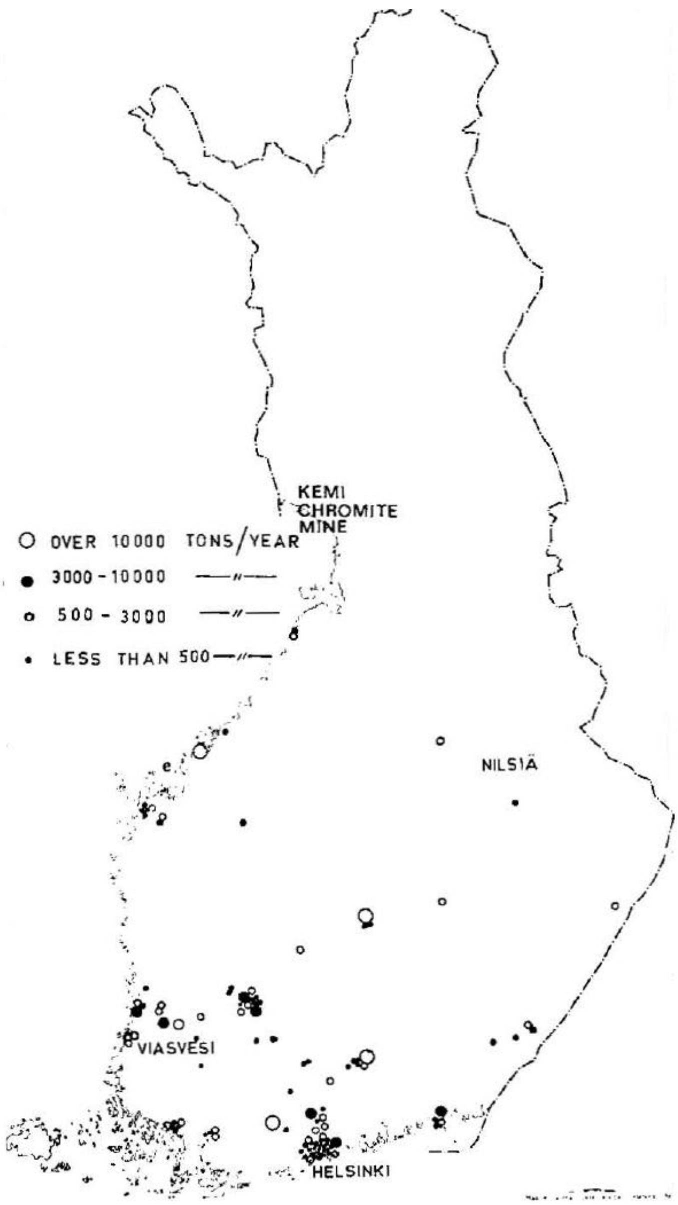

Fig. 1: The location of Finnish foundries and main sand deposits (Autere, 1976)

1.4.2 Composition of foundry sand

The sand used in foundry are quartz sand. More the quartz amount in the foundry sand, better it is. The foundries use inorganic and organic binders, different additives, and variety of sand composition for casting process (Benson et al. 2011). Foundry sands that are generally used in Finnish foundries are green sand, alkaline phenolic sand and furan sand. Binders are kind of glue that bind sand grains to give definite shape. The binders are of two types- organic and inorganic. Theoretically, all the organic materials (binder, additives, and coating) should have gone to thermal degradation and oxidation. In practice, because of complexity and unpredictable nature of combustion, complete degradation does not occur. (Winkle et al.

2000). The surplus foundry sand generated during casting contains metals from casting and the organic compounds from binders. Such residue, dust and other fine grained foundry waste mixed in the process can limit the reusability of the surplus foundry sand.

1.4.3 Scope of literature review

This work reviews most of the published literature on reuse possibility of surplus foundry sand in composting. Besides this, it aims in reviewing articles and journals on reuse possibility of SFS in other areas such as earth construction, in production of ceramic bricks, use as low-cost adsorbent material for Cr (VI) removal etc., published till December 2015. Most of the information reviewed are complete and available to the public. Whereas, others are in research phase. This approach creates some incompleteness in detailing but the major conclusion drawn is similar.

1.4.4 Potential contaminants in foundry sand

Variety of organic and inorganic binders are used in foundries to prepare moulds and cores. These binders are retained in the surplus foundry sand, so numbers of tests are conducted to characterize foundry sand and to measure the environmental impacts of reusing them. The common test is Toxicity Characteristics Leaching Procedures (TCLP) that measures the various constituents in sand that could leach in contact (U.S. EPA, 2002). This TCLP test analyses 8 primary metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver) and 4 secondary metals (copper, zinc, iron and manganese) listed in drinking water standards (Orkas, 2001). The pH-static test on alkaline phenolic sand and furan sand measures the leaching behaviour of chromium. The pH variations in the environment has huge impact because small change in pH leads to significant change in leachability (Orkas, 2001). Screening test indicates the presence of heavy metal contaminants and organic compounds in sand. The quantity of heavy metal concentration in surplus foundry sand and virgin sand are generally of same amount (Winkler et al. 2000). As mentioned earlier, foundry uses binder which is the key source of organic contaminants (U.S. EPA 2002). Binders that contain harmful compounds and are used in Finnish foundries in alkaline phenolic sand are: formaldehyde, phenol, 4.4-isopropyldenephenol, propylene carbonate, ethyleneglycolmonophenylether, methanol, methylformiate, diphenyl-4,4-di-isocyanate, N,N-dimethylethylamine, hexamine, cryolite and isopropanol. Similarly, green sand uses phenols, formaldehyde, isoforon-di-isocyanate, diphenylmethan-di-isocyanate and metals such as chromite (Orkas, 2001). On the basis of harmful components in the binding agents, the characteristics of surplus foundry sand are studied using GC-MSAD method that determines PAH and screening of organic compounds. The phenol concentration is analysed by SFS3011 (Orkas, 2001). Green sand casting process, which commonly does not use organic binder, has lower potential in leaching organic compounds than the one using organic binder (Siddique et al. 2011). During the casting process some of the organic binders can alter from their original composition, due to incomplete combustion, and form new hazardous compounds (U.S. EPA, 2002). Phenolic urethane and phenolic isocyanate are environmentally concerning binder systems because they contribute more organic content than any other binder systems. The freshly prepared moulds and cores that have not been in contact with hot molten metal should be separate from surplus foundry sand. The unreacted binders in these moulds and cores have high potential of leaching organic materials (Winkler et al. 2000).

1.5. Legislation

1.5.1 Definition of by-product

The waste is leftover from production and consumption which is produced unintentionally. The legal concern related to the waste e.g. the responsibilities, the transfer, the shipment and treatment of the waste are subject to laws and regulations. It is because the waste or by-products can be recovered and might have economic values (Mroueh, 2000).

The Finnish Waste Act (646/2011) does not refer to the term ‘by-product’. According to the EU waste directive (2008/98/EC), waste refers to “materials, things or a structure whose owner has intents to remove from use”. The helpful interpretation for defining waste is obtained from European Waste Catalogue (EWC), which has been published in Finland as decision (867/1996) by the Ministry of the Environment, and also the interpretation practice of the court of the EU. Although the EWC has defined waste, it does not give real guidance because according to the decision stated in EWC, the things listed in the list are not necessarily waste but if they are not included in list then they might be waste (Mroueh, 2000).

On the basis of the various EU court decision, a guideline has been used to classify the by-products that are not covered by the waste directive. Figure 2 below illustrates the decision tree used to classify waste and by-products.

At the moment, the surplus foundry sand which is the by-product of foundry is referred as waste, according to the Waste Act, and regulation concerning waste in the Waste Act and in the Environment Protection Act. So far, Finnish legislation is not familiar with the term product development by which the materials could bypass the application of the waste law. Some kind of product development is possible on the basis of the decree of the ministry of agriculture and forestry on fertilizer products (24/2011) which can only apply to fertilizers and soil improvements (Mroueh, 2000).

The aim of fertilizer product act (539/2006) is to provide safe fertilizer products that ensure plant protection, quality food stuff and environment. Composts are organic fertilizers. According to this act, the compost produced or raw material used may not contain harmful substances, products or organisms in such quantities that their presence may cause danger to human health, plant or environment. The compost and raw material should fulfill the quality requirement set for them. The raw materials used in compost should be mentioned. The contents and other ingredients are declared as a percentage by weight of dry matter (%-DM). The nutrients contents must be declared as elements, and as oxides. The micro nutrients contents should be also be declared. The total amount of organic carbon (TOC) as a percentage of dry matter, amount of water soluble nitrogen and phosphorus also must be declared. The detail information about permitted contents of nutrient in compost is given in appendix 1. To make assurance to the potential end users, it is necessary to collect sample of arable land before using compost prepared by using surplus sand and sample of arable land after using compost for 5 yrs. The test should carry pH test under SFS 3021, heavy metal test under SFS-EN 13346 and for mercury, a test under prCEN/TS 16175-1. (Government decree on fertilizer products act, 2006)

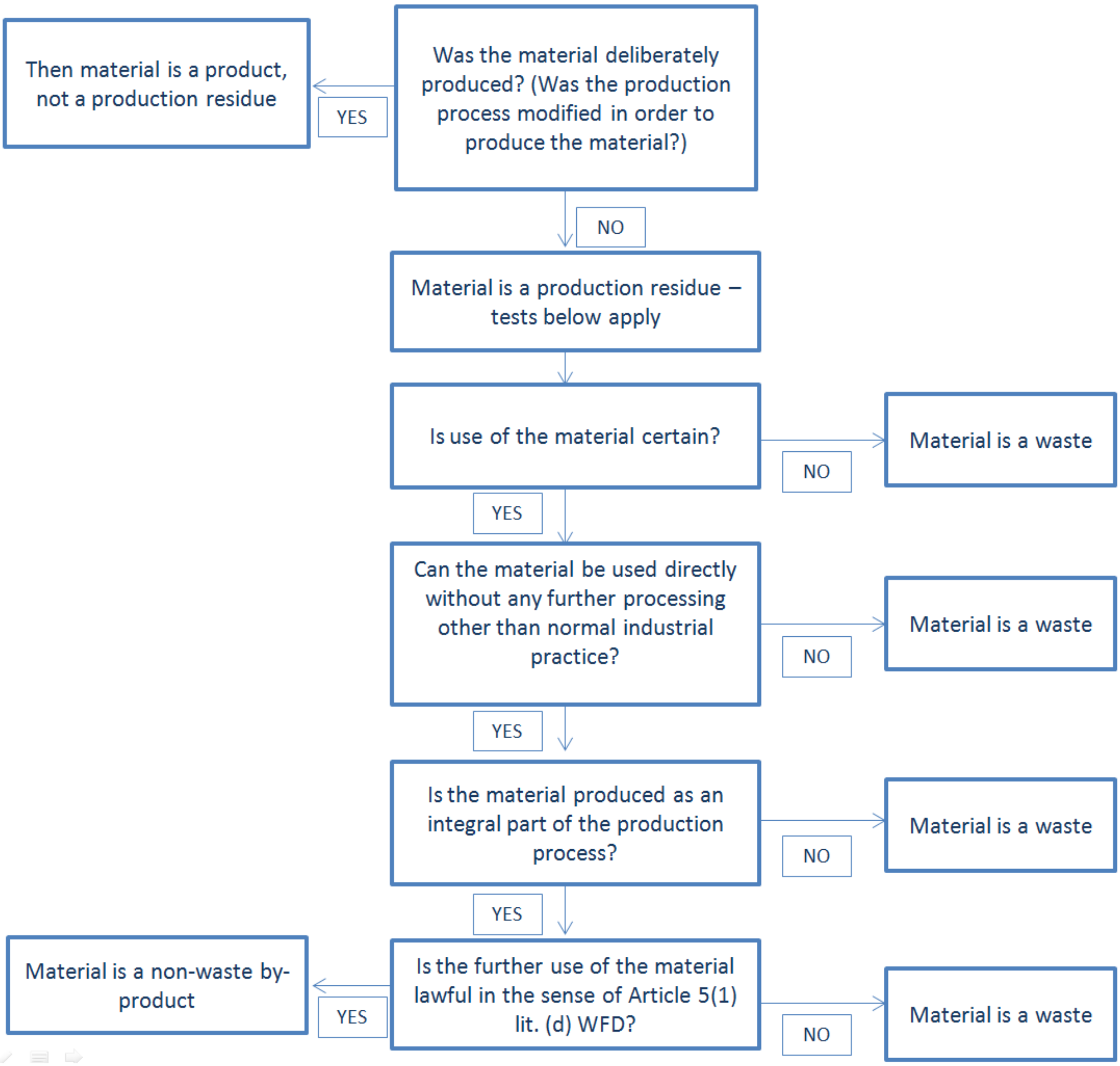

Figure 2: EU decision tree on the classification of waste and by-products (Directive 2008/98/EC, 2012)

1.5.2 Environmental permit requirements for the use of the foundry sand

The environmental permits for the use of surplus foundry sand in composting is based on 28.2 section 4 of the Environment protection Act. The environmental permit must be applied for the plant or professional using or handling the waste". In practice, the basis of the permit requirements for the use of surplus foundry sand in composting is same in this respect as in the repealed Waste Law, section 42.

An application to get an environmental permit for the use of surplus foundry sand for different purposes is made to the local environmental protection authority. And the amount handled, utilized and deposited should be below 5000 tons per year. If the amount exceeds 5000 tons, the permit is given by Regional State Administrative Agencies (RSAA)

(Environmental Protection Statute 6 section 12 d). The time taken to process the permit is minimum 4 months (Mroueh, 2002).

In order to apply for an environmental permit, applicant must provide previously conducted surplus foundry sand characterization report, supplemented with quality control data to show environmental compliance that would supply adequate information to the environmental authorities. In addition to filling in the form, it is recommended according to the environmental protection statute section 12 to present necessary appendices that include the following information for surplus foundry sand:

- Information concerning the amount and quality of the surplus foundry sand to be deposited (Environmental protection Statute 12 section 1)
- Facts regarding the location and ground water resources of area (Environmental protection Statute 12 section 12.2)
- Structural explanations and diagrams
- Document on the environment compliance and material to be deposited
  - Comparison of concentration of harmful components with acceptance criteria
  - Sampling methods and test methods that have been used in the evaluation of the leaching of the harmful components, comparison of the test results with the standards and authorized person for test
  - Other potential harmful materials to the environment or the relevant research document
  - Results of the risk assessment
  - Quality control of the environmental compliance research

According to the law, the user must preserve the records on the quality, amount of origin, deposit location and method of handling of the surplus foundry sand. In permit decisions the applicant must inform the permit authority about the deposited materials, their amount and technical implementation in composting, after surplus foundry sand has been deposited (Mroueh, 2000). The record of the surplus foundry sand quality is obtained from the foundry.

According to the Finnish government regulation on landfills (331/2013) section 20 compliance testing, the foundry should monitor the quality of the surplus foundry sand. Foundry needs to test surplus foundry sand to obtain the data related to basic characterization of the composition and the solubility characteristics of surplus foundry sand as mentioned in section 25 of government regulation on landfills (331/2013). Since surplus foundry sand in foundry is regularly generated waste it is subjected to compliance testing as mentioned in section 19, and does not therefore require regular testing of waste batches. The compliance testing i.e. mentioned in section 20 shall be repeated at least once a year to show that surplus foundry sand produce meets the threshold value set. The foundry should keep record of compliance testing at least for three month from the date of receipt.

1.6 Applicability research

The types of surplus foundry sand, foundry process they were used under and the properties of the surplus foundry sand affect the reuse applicability of surplus foundry sand. The chemical, physical and biological properties such as concentration of heavy metals, toxic materials, their properties and composition also affect in the technical appropriateness and environmental requirement. Therefore, planned assessment of applicability must be executed to consider the factors and their interactions whenever necessary (Mroueh, 2000). These planned assessments would help to find the stability of surplus foundry sand and their effects to health and the environment.

The literature review on beneficial reuse of surplus foundry sand shows wide research being done to find the best possible reuse of surplus foundry sand. Among a number of proposed beneficial reuse possibilities of surplus foundry sand, few are economically feasible except if foundry and reusing sites are close to each other. This would decrease the transportation cost for treatment and reuse. Several studies have indicated the following reuse possibility of surplus foundry sand:

Portland cement: Portland cement is a bonding material. It is produced from ground limestone and clay material. Calcium silicate is one of the main compounds present in Portland cement. Surplus foundry sand is almost pure silica. Therefore, there is huge possibility for using surplus foundry sand in preparing Portland cement.

Portland cement concrete: According to Javed et al. (1994), Portland cement concrete consists of 30% sand, 50% gravel, 15% cement and 5% water. The research in this reuse possibility concluded that the Portland cement concrete can be manufactured replacing partial amount of virgin natural sand by surplus foundry sand.

Flowable fill (low strength concrete): Flowable fill is common material used in structural and highway application. Virgin sand are huge components used in most flowable fill mixes.

Javed et al, (1994) have mentioned that if surplus foundry sand can be supplied free of charge, flowable fills that include surplus foundry sand would be inexpensive.

Asphalt concrete: Generally, asphalt concrete is used for construction of highway and roads. It consists of 5% bitumen, 95% graded particles that contain fine sand to 20-30 mm gravel. The fine particles can be as much as 15% of asphalt concrete. This shows the potential to replace fine materials by surplus foundry sand (Regan et al. 1997).

Minerals liners: There is stricter rule set by the waste management act and the EU directives on landfills for preventing leaking of any hazardous substances into ground water and water ways from landfills. Therefore, water-tight liners are constructed from soil and bentonite. According to Orkas (2001), use of surplus green sand with active bentonite provides inexpensive landfill liners. Surplus foundry sand from foundries can be used for covering landfills.

Soil blending and sports turf application: McCoy et al. (1998) came to conclusion that foundry sand and peat used as blend ingredients support turf growth without addition of virgin sand. McCoy stated that sand-peat humus blends provide balance between high water and nutrient retaining. This proves that there is a higher potential to use SFS as an ingredient in topsoil blends used for landscaping and sports turf application.

Ceramic bricks production: Alonso et al. (2012) has mentioned that surplus foundry sand from 35% green sand and 25% core sand mixed with clay and treated at 850-1050 ^{0}C produces ceramic bricks. These ceramic bricks have good physical properties and no significant effects on mineralogy. It is demonstrated in article that surplus foundry sand can be used partially as a clay substitute in ceramic brick productions.

Use as a low-cost adsorbent material for Cr (VI) removal: In modern industries, large amount hexavalent chromium Cr (VI) are discharged into the environment due to its wide use. Most of the methods used to control the discharge of Cr (VI) are expensive due to operational, treatment and sludge disposal cost. Adsorbent is an alternative treatment for removal of heavy metals (Campos et al. 2013). Campos et al. (2013) have stated that use of foundry sand as absorbent can remove Cr (VI) from the industrial sewages in lower cost.

The beneficial reuse mostly includes construction applications while agriculture reuse is limited due to the impression that surplus foundry sand might have adverse effects on human health rather than to the environment. Therefore, huge research is needed to bring awareness that surplus foundry sand is completely similar to virgin sand.

1.6.1 Factors which affect the applicability of the surplus foundry sand

The crucial motivating factor for reusing of surplus foundry sand for composting is saving costs and time rather than protecting environment and natural resources. If foundries need to dispose their surplus sand, they need to pay for transportation and tipping of fees. Therefore, foundries always compare the cost required to dispose in landfill and the cost required to segregate to make it reusable for composting. In case of potential end users, cost of virgin sand is considered against the cost of surplus foundry sand including any test performed and the time consumed. Even though the sand and gravel resources of the world are large, due to the geographic distribution, environmental restrictions and quality requirements for the extraction of sand from the resources are uneconomical for foundry use (USGS, 2015). So far very less studies have been done in reuse possibility of surplus foundry sand; due to the stricter rules, it requires tedious paper work and test that might increase the cost to the foundry and the end user. The doubt on properties and composition of surplus foundry sand that might have negative impacts on climate, long-terms changes in environment (for example pH changes), and adverse effect on soil, water, plant, animal and people. Inability to provide sufficient amount of sand for certain uses, for example, earth construction which requires huge amount of sand and it is difficult for small foundries to fulfil their demand.

1.7 Compost

1.7.1 Technical compost standards

Compost is an organic material that has basically good material in soil (humus) that sustains plant life or help plants grow. Most of the materials that we send to landfills that come from household, industries and offices could be used in agriculture. According to the project description of LIFE13 ENV/FI/285 "Foundry sand" (2014) in Europe, 18 million tons of surplus foundry sand is produced every year and requires huge landfills if we will fail to find alternative solution to dumping. Compost produced due to biodegradation of organic matter with or without the help of human being has wide range of benefits to environment and mankind.

- Compost helps to retain moisture in soil, which will reduces the loss of water and leaching.

- Assist with the formation of good soil structure i.e. rich in nutrients, provides beneficial microorganisms to the soil which improves the plants ability to resist disease.
- Composting helps to breakdown specific pollutants, such as VOCs, heavy metals and toxics chemicals such as pesticides and herbicides.
- Composting prevents waste going to waste.
- Reduces the greenhouse gas emissions that might cause due to biodegradable waste under landfills i.e. methane which is 30 times as harmful as carbon dioxide gas as a greenhouse gas. Figure 3 illustrates the emissions from landfills and affecting areas.

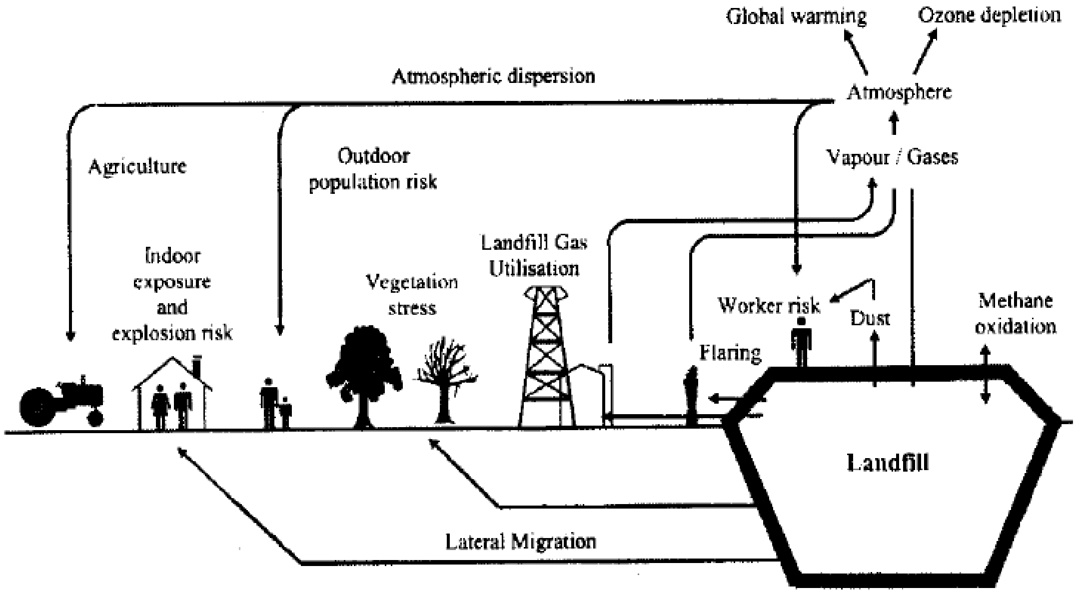

Figure 3: Emissions from landfills and its affecting area (Gregory et al.1999)

- It promotes the organic farming that would benefit human health and economy in long run. (USGS, 2015)

The compost is the end-product of biological treatment process and needs a certain type of ‘process related’ standard that defines the quality of the compost. Standards for the feedstock and process used help to maintain the standard of the end product. Only through different tests, heavy metal contain, toxicity and sanitation of compost can be examined. The compost products can be used in agriculture sector, landscaping, hobby gardening, horticulture, earth works, land-restoration, export, etc. These different area demands diverse parameters on maturity, conductivity, particle size and nutrient content. For example, horticulture and agriculture requires higher standards than for landscaping and landfill-restoration.

The most common standard used across Europe limits the potentially hazardous materials such as heavy metals, fluoride, phenols, DOC etc. Other different standards used such as Jann test, Creed seed test help to reduce pathogens and increase germination respectively.
These different standards set acts as the quality assurance tools that guarantee the quality and safety for end-users. In case of producers, such regulation acts as promotional tool that promotes the higher quality product in market. (Hogg, et al. 2002)

1.8 Composting process and technical problems

Composting is an aerobic decomposition of organic wastes under controlled conditions to get a stabilized, humus rich soil (BC compost fact sheets, 1996). In compost, microorganisms such as bacteria, fungi and actinomycetes consume oxygen (O_2) and convert the organic matter into stable humus as illustrated in Figure 4 (Pace, et al. 1995). The acceleration of decomposition that occurs in composting can be improved by human intervention (BC compost fact sheets, 1996). Figure 4 illustrates the basic composting process.

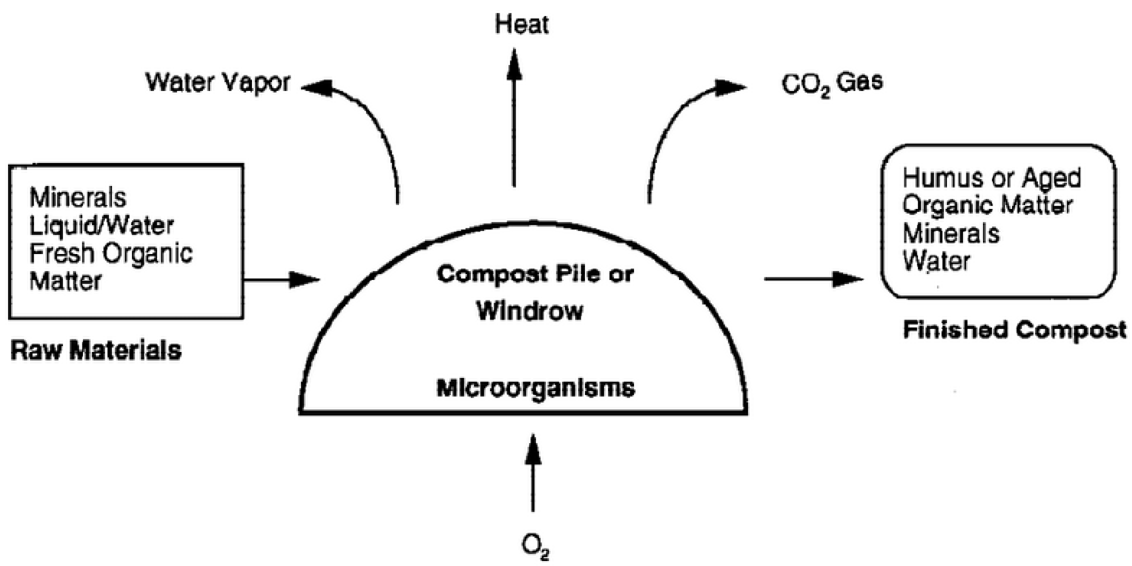

Figure 4: The composting process (Pace, et al. 1995)

The biological activities in composting takes place in three phases:

- Composting initiates as soon as raw material get mixed. The bacteria consume the easily available sugar and oxygen in heaps which will rapidly increases the temperature as high as 70-80 ^{0}C.
- In next phase cellulose are break-down by bacteria and actiomycetes.
- At the end tougher lignin are break-down by fungi which cools the compost heaps. (Hogg, et al. 2002)

To make effective composting, it requires five key factors, they are- temperature, air supply to heaps, moisture content, the porosity of the material and the carbon to nitrogen (C: N) ratio of heaps. (Hogg, et al. 2002)

During composting, abundant attention should be paid to ensure that sufficient reduction of pathogen levels occurs reaching specific temperature of the heaps for certain time. This implies necessity of some monitoring. Another problem is related to the placement of compost facilities because of the odour related issues. Final problem is related to the nature of material composted. Material being composted determines the quality of the composts and composting material should maintain the quality of compost that meets the market standards in order to achieve market reliability. (Hogg, et al. 2002)

1.9 Conformity and disagreement in existing compost standards

As the political and industrial development and rise in the organic farming have taken place, the assessment of compost quality has gradually evolved in the world. In a number of areas the agreement between the countries are similar and in some other areas it is different.

Standards set by the different countries have same basic purposes of setting out agreed norms so that their people can be assured about the services, product they use. The standards vary on the basis of agreement and on the basis of number of countries involved. Table 1.9 illustrates the similarity and the differences between the methods and common acceptance on compost standards.

First column in Table 1.9 shows that participant countries have set the compost quality on the basis of heavy metals, physical description, density and porosity, foreign contaminants like plastic, stone, on the basis of hygiene, plant growth etc. whereas mid column in Table 1.9 shows level of agreement between different countries, i.e. at what level different countries have agreed to achieve the set compost quality standards. For example, in case of heavy metals, USA has difference in opinion with other participant countries. Similarly, it shows that many participant countries have poor plant hygiene standards compared to Germany. There is also mentioned about agreement between the countries in improvement of the method used to test plant growth, stability test. The last column of Table 1.9 describes the changes that USA needs to do in their standard to reach the general agreement. For example, USA needs to changes EPA503 rule on metals. USA has no plant hygiene standards set which needs significant research and frame work and more methods are needed to develop for performing plant growth and stability test.

Table 1.9 Compost quality attribute and agreement between different counties (Brinton, 2000)

Compost Quality Category	Level of agreement between various countries	Change needed to reach general accord
Heavy Metals	USA discordant in regards all other countries	Significant: Adopt two levels - Class I (low metals) and Class II (elevated metals) - or- - abandon EPA503 rule
Physical Description	little data on test frequency	Moderate: determine ranges
Density and Porosity	few developed standards	None: support voluntary reporting of traits
Stones vs. plastic and other inerts as % of fry matter	generally good agreement	None: adopt description scheme with set limits
Hygiene:		
Facility / Worker	Poor - some countries very low standards	Significant: adopt research framework
Plant - Phyto	Germany alone with plant hygiene standards	None: support voluntary reporting where needed
Potential mammalian pathogens	Good agreement re: Salmonella & coliform	None: adopt description scheme with set limits
Plant Growth	Generally good; weak development of methods	Moderate: support research & voluntary reporting of performance;
Weeds	incomplete methods; contamination not defined adequately	Moderate: evaluate methods and determine "clean" level
Maturity / Stability	Generally good; many methods at research level need development	Moderate: more methods need to be recognized and correlated

The difference in opinion between participant countries regarding set standards is due to the chaotic relationship of social and political forces, different scientific opinions on technique to perform test on compost and defined critical level of materials with respect to the harmfulness to environment (Brinton, 2000). In some countries, compost standard might be set as the advice and guidance whereas in some other countries, it might be set as absolute requirements.

2. Materials and Methods

2.1 Analysis of the hazardous material of surplus foundry sand

Thesis study mainly focuses on green sand, furan sand alkaline phenolic sand used in Finnish foundries. The possible harmful compounds used in Finnish foundries are shown in Table 2.1 (Orkas, 2001).

Table 2.1 Sand used in Finnish foundries and possible harmful compounds in sand binding agents collected from the foundries (Orkas, 2001).

Types of Sand	**Harmful Compounds**
Green sand	Phenol, formaldehyde, isoforonic isocyanate, metals (from chromite sand), mineral oils, polymethyl-siloxane, heptane, Diphenylmethane-4,4-diisocyanate and aromatic, hydrocarbons, 3,4,4,-trimethyl-2-cyclohexene-1-one, isopropyl alcohol, dimethyl isopropyl amine, trimethylamine, hexamine
Alkaline phenolic sand	Furfurylalcohol, formaldehyde, phenol, toluene sulfonic acid, metals(chromite sand), urea-formaldehyde resin, benzene sulfonic acid, p- toluene sulfonic acid, sulfuric acid, xylene sulfonic acid, sodium silicate
Furan sand	Formaldehyde, phenol, phenol resin, 4,4 –isopropyldenephenol, propylenecarbonate, ethyleneeglycolmonophenyether, methanol, methylformiate, diphenyl-4,4-di-isocyanate, N,N-dimethylethylamine, hexamine, cryolite, isopropanol

2.2 Development of the quality control system for surplus foundry sand

Orkas (2001) reported that, according to the criteria set for different re-use types of the surplus sands that were based on target and limit values set for the assessment of soil pollution, some analyse surplus foundry sand from foundries considered to be safe for re-use purposes. Lindsay et al. (2005) also stated that, according to the criteria set by the USEPA, only small percentage of the excess foundry sand was characterized as hazardous waste. Even though the majority of the surplus foundry sand is non-hazardous, it is estimated that a large part of the surplus foundry sand is discarded in municipal or private landfills and small portion is re-used outside foundry industries. On one hand, this increased the expenses of the foundries and, on the other hand, the dependency in consumption of virgin sand increased. Different research that is based on the beneficial uses and markets of the surplus foundry sand have evaluated that surplus foundry sand has nearly all the properties of natural and manufactured sands. This shows that surplus foundry sand can be used as the replacement sand in different area such as (Siddique, et al. 2011).

- Agriculture use, e.g. top soil blending and compost production
- Foundry sand that can be used as e.g. the low-cost adsorbent materials for Cr (VI) removal
- Civil engineering application, e.g. embankment, flowable fills, Portland cement concrete and hot mix asphalt
- According to the U.S. department of transportation Federal highway administration, the quality of the foundry sand can be measured by
- Durability and soundness of the surplus foundry sand that is based on the rate of recycle in foundry and how it was used in foundry
- Chemical composition that is based on the metal moulded at foundry which defines the binder used and combustible additives
- Variability that is based on consistency of binder used and combustible additives used in the different foundries

Orkas (2001) addressed all influencing factors that affect the quality of the surplus foundry sand mentioned by U.S. department of transportation Federal highway administration. He also included all determining factors while developing individual quality control systems for two selected foundries that use alkaline phenolic sand and green sand, after evaluating the variations in the quality and the composition of the sand at different points used in the foundry.

According to Orkas (2001), characteristics such as eluate pH, ignition loss, semi-quantitative X-ray fluorescence spectroscopy analysis (XRF), polyaromatic hydrocarbons (PAHs), phenol concentration and screening of organic compounds were studied to know the acidity of the material, amount of incombustible binding agents, rough estimation of composition and total amount of phenols. Different methods were used such as GC-MSD analysis, Sim-technique, distillation, de-mineralization of water etc. The proposed acceptance criteria of the studied parameters like eluate pH, phenol index, PAH compounds and total, screening of compounds and heavy metals for different utilization for example class 2: earth construction covered by soil (over ground water table, not on groundwater area) and class 3: earth constructions covered by water–impermeable materials, e.g. asphalt, were tested using different test and analysis against the standard values. Orkas (2001) also states that to ensure the quality of the surplus foundry sand for class 2 and class 3 uses, the foundries should frequently test their surplus sand based on the capacity of production in the foundries shown in Table 2.2.1.

Table 2.2.1 Quality control sampling frequency for different size foundries (Orkas, 2001)

Amount of the foundry sand produced	Sampling frequency	Sub-sampling
< 1000 ton/year	At least 2 sampling periods per year At least 3 sub-samples are collected per each sampling period during a time of at least 3 weeks, which means one sub-sample per week preferably on different working days. Only in cases where the production is shown to be stable with small variations in sand quality, can collect all samples during same week.	A laboratory sample is prepared from at least 3 sub-samples.
1000-5000	3 sampling periods in a year	
5000-10000	4 sampling period in a year	
>10000	5 sampling in a year	

According to the specific regulatory requirements, Kurtz brothers in Ohio that incorporates, produces and sells variety of soil blending products and compost that is prepared by using surplus foundry sand should adhere to the following conditions:

- Annual testing by surplus sand producer of the leachate from its surplus sand using Toxicity Characteristic Leaching Procedure (TCLP) or additional limits for lead and phenol, and if producer changes its manufacturing process or the material used in the production, it must test the leachate from the new process or material to verify that no limits are exceeded (U.S. EPA, 2002).
- Quarterly TCLP testing by compost producer of the final soil amendment products containing foundry sand must be monitored quarterly for nine metals and must meet the limits that are equivalent to twice the limits in standards (U.S. EPA, 2002).

- Submission of an annual report from compost producers to authorities that should include at a minimum: 1) the annual report of TCLP monitoring of the foundry sands; 2) the quarterly results of the total metals monitored in soil blends; 3) reporting existence of any “hindrances” in the project (e.g. spill) and 4) the results of any research on foundry sand recycling conducted by compost producers (U.S. EPA, 2002).

The existence of this kind of regulation considerably saves time and money, reduces the paperwork required for reuse of the surplus foundry sand and motivates foundries to improve quality of surplus foundry sand and the end users to use it.

3. Results

3.1 Analysis of the hazardous material and its variation in surplus foundry sands

The result acquired from the first phase of surplus foundry sand analyzed prior to mixing into test compost windrows conducted in June 2015 is presented in Table 3.1, Table 3.2 and Table 3.3. The Table 3.1 illustrates especially the existence of water soluble heavy metals in surplus foundry sand. The Table 3.2 shows the presence of pH, PCB, phenol, BTEX, PAH, hydrocarbons and other concerned materials. The regulation limits used were non-hazardous inert waste (331/2013). The Table 3.3 presents total metal concentration in green sand, phenol sand and furan sand used in composting. The regulation limits used were from Decree of the ministry of agriculture and forestry on fertilizer products, (24/2011).

Table 3.1 Water soluble metals in sand samples in the summer 2015 composting tests of the LIFE13 ENV/FI/285 "Foundry sand" project (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Analysis substance (symbol)	**Green sand value mg/kg dm**	**Phenolic sand value mg/kg dm**	**Furan sand value mg/kg dm**	**Non-Hazardous Inert waste Landfills (kaatopaikka (331/2013))**
Aluminium (Al)	28	12	31	-
Antimony (Sb), L/S = 10	<0.01	<0.01	<0.01	0.06
Arsenic (As), L/S = 10	0.02	<0.01	<0.01	0.5
Barium (Ba), L/S = 10	0.01	0.02	0.26	20
Cadmium(Cd), L/S = 10	<0.003	<0.003	<0.003	0.04
Chrome (Cr), L/S = 10	<0.01	<0.01	0.13	0.5
Copper (Cu), L/S = 10	<0.05	<0.05	<0.05	2
Lead (Pb), L/S = 10	<0.01	<0.01	0.04	0.5
Molybdenum (MO), L/S = 10	0.09	0.08	<0.01	0.5
Nickel (Ni), L/S = 10	<0.01	0.03	0.12	0.4
Iron (Fe), L/S = 10	<0.1	3.2	76	-
Selenium (Se), L/S = 10	<0.01	<0.01	<0.01	0.1
Zinc (Zn), L/S = 10	<0.1	0.5	0.4	4
Mercury (Hg), L/S = 10	<0.002	<0.002	<0.002	0.01

- = There is no limit value for the parameter.

Table 3.2 Other chemical composition of studied sand samples in the summer 2015 composting tests of the LIFE13 ENV/FI/285 “Foundry sand” project. (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Analysis	unit	Green sand	Phenol sand	Furan sand	Non-Hazardous Inert waste Landfills (kaatopaikka (331/2013))
BTEX	mg/kg dm	0.72	0.18	7.68	6
16 EPA-PAH	mg/kg dm	0.61	1.06	n.c.	40
Chloride(Cl), L/S=10	mg/kg dm	31	<10	<10	800
Sulphate	mg/kg dm	290	34	340	1000
PCB	mg/kg dm	n.c.	n.c.	n.c.	1
Hydrocarbons C10-C40	mg/kg dm	87	<40	<40	500
Total organic carbon (TOC)	%	1.9	1.1	4.5	3
pH	mg/kg dm	8.3	9.1	3.3	-
Fluoride (F^-), L/S = 10	mg/kg dm	53	43	<5	10
DOC, L/S = 10	mg/kg dm	11	1200	780	500
Phenol index, L/S = 10	mg/kg dm	<0.1	1.8	0.61	1

n.c. = cannot be calculated, as the analysis of the results of all the individual compounds are below the detection limit

- = parameter does not have limit value

Note: the values that exceed the limit values are highlighted with yellow color.

Table 3.3 Total metal concentration in green sand phenol sand and furan sand (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Total metal concentration	**Unit**	**Green sand**	**Phenolic sand**	**Furan sand**	**Fertilizer regulation limit value (24/2011)**
Aluminium (Al)	mg/kg dm	6100	1000	770	-
Antimony (Sb)	mg/kg dm	<1	<1	<1	-
Arsenic (As)	mg/kg dm	1.4	<0.8	<0.8	25
Barium (Ba)	mg/kg dm	71	6	6	-
Cadmium (Cd))	mg/kg dm	<0.2	<0.2	<0.2	1.5
Chromium (Cr)	mg/kg dm	16	8	2	300
Copper (Cu)	mg/kg dm	92	6	12	600
Lead (Pb)	mg/kg dm	5	<2	<2	100
Molybdenum (Mo)	mg/kg dm	<2	<2	<2	-
Nickel (Ni)	mg/kg dm	11	12	1	100
Iron Fe)	mg/kg dm	15000	4000	1300	-
Selenium (Se)	mg/kg dm	<1	<1	<1	-
Zinc (Zn)	mg/kg dm	160	54	10	1500
Mercury (Hg)	mg/kg dm	0.64	<0.07	<0.07	1

- = *There is no limit value for the parameter*

The first phase of the surplus sand analysis draws following conclusions:

- All the heavy metals in surplus foundry sand are below the standard value.
- The dissolved organic compounds (DOC) value of green is far less but the DOC value of furan sand and alkaline phenolic sand is elevated than the standard value.
- The fluoride value is elevated in green sand and alkaline phenolic sand by about 500% and 400 % respectively whereas in furan sand, it is less than 5 mg/kg.
- The studied samples showed the presence of phenol which is below the standard value in green and furan sand samples but are higher in alkaline phenolic sand sample.

- According to the non-hazardous inert waste (331/2013) there is no threshold value of pH but the test samples showed that all sands has pH therefore for comparison limit value of non-hazardous ordinary waste (331/2013) is marked and graphically presented in Figure 5.
- The presence of BTEX amount is elevated in furan sand but is lower in green and phenolic sand samples.
- The existence of PCB, chloride, hydrocarbons, PAH and sulphate are less than the threshold value for non-hazardous inert waste (331/2013)
- The total metal concentration in all tested surplus foundry sand samples used for composting was below the limit value.

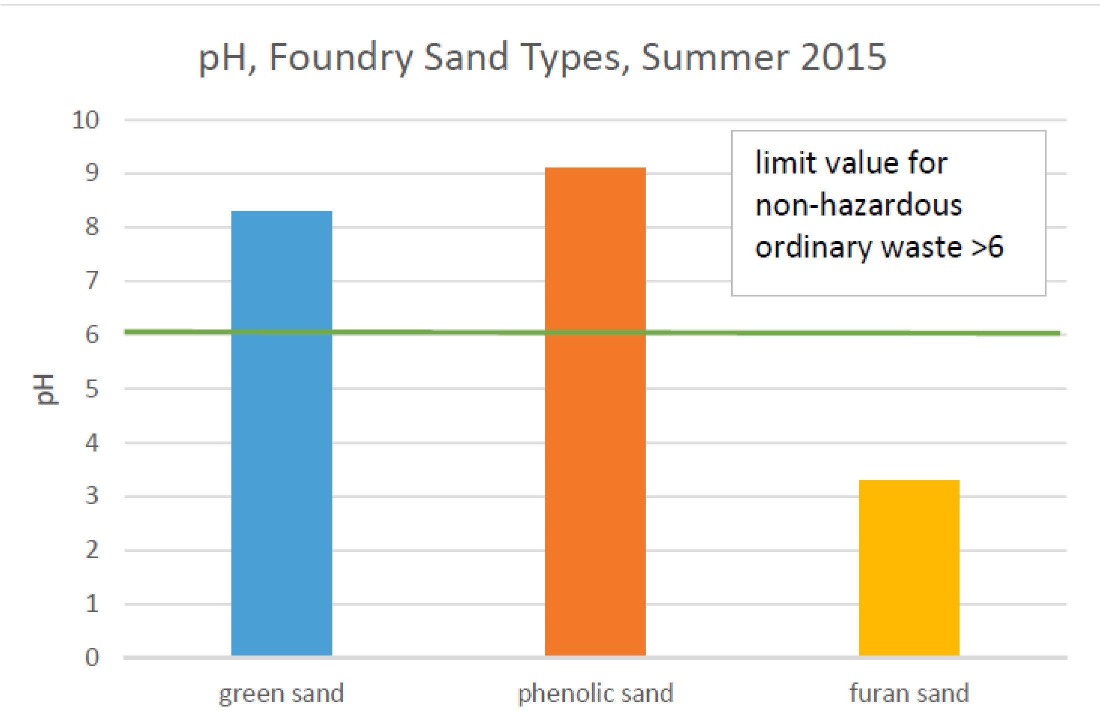

Figure 5: pH value of three different surplus foundry sand samples (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Graphical representation in Figure 6 shows pH values of six different compost test heaps prepared from three different sands. The 1st test result exhibits that pH value of compost prepared from green and alkaline phenolic sand is less than pH value of their respective sand but pH value of compost prepared form furan sand increases above threshold value. The 2nd phase test demonstrates that pH value of all the compost decreases from the first. The final stage test shows that for green and alkaline phenolic sand compost, the pH value increases but for furan sand compost, it continues to decrease.

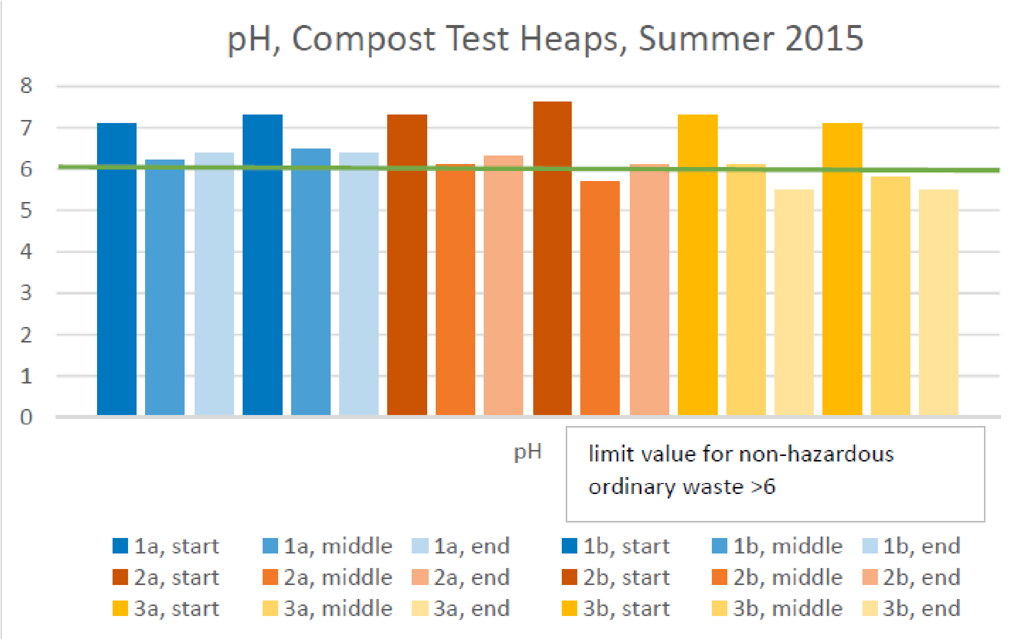

Figure 6: pH value of 6 different composts measured in three phases (1a and 1b = green sand, 2a and 2b = phenol sand and 3a and 3b = furan sand heaps) (LIFE13 ENV/FI/285 "Foundry sand", 2016).

From initial test it is known that waste water sludge used as composting materials has high concentration of DOC, sulphate and phenols before mixing with other composting material and surplus foundry sand.

The Figure 7 illustrates the level of dissolved organic compound (DOC). The graphical representation shows that amount of DOC is minimum in green sand. But the 1st test result of two different compost test heaps prepared from green sand demonstrated elevated DOC amount in compost that might have caused due to use of waste water sludge. The 2nd and 3rd phase test result exhibits that the amount of DOC amount decreases below threshold value. This concludes that composting will decrease the elevated DOC amount that existed at the beginning.

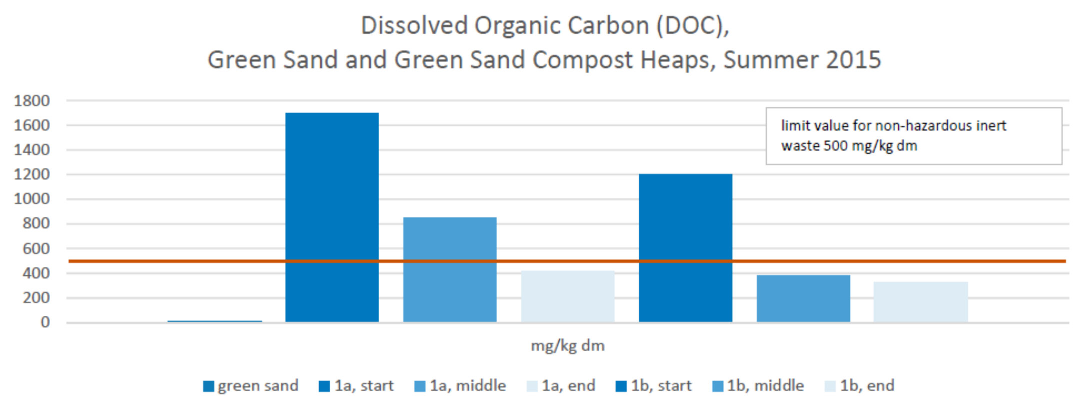

Figure 7: DOC value of Green sand and two different kinds of green sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

The Figure 8 illustrates the level of dissolved organic compound (DOC). The graphical representation shows that amount of DOC is elevated above threshold value in alkaline phenolic sand. The 1st test result of two different compost test heaps prepared from alkaline phenolic sand demonstrated much elevation on DOC amount in compost that might be due to use of waste water sludge. The 2nd and 3rd phase test result exhibits that the amount of DOC decreases below threshold value. This concludes that composting will decrease the elevated DOC amount that existed in alkaline phenolic sand and compost in first phase.

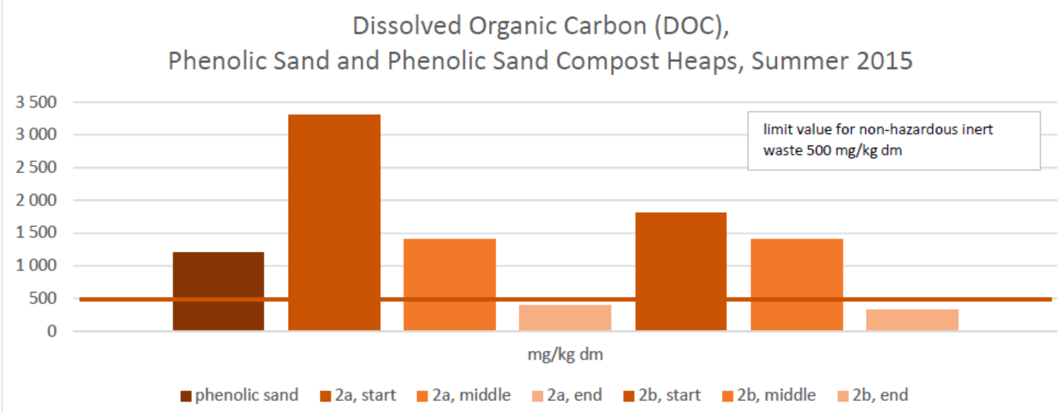

Figure 8: DOC value of alkaline phenolic sand and two different kinds of alkaline phenolic sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 9 illustrates the level of dissolve organic compound (DOC). The graphical representation shows that amount of DOC is elevated above threshold value in furan sand. The 1st test result of two different compost test heaps prepared from furan sand demonstrated much elevation on DOC amount in compost that might have caused due to use of waste water sludge. The 2nd phase test result exhibits that the amount of DOC decreases near to the threshold value. The 3rd phase report illustrated decrease of DOC amount for group “a” compost but for group “b” compost DOC amount increases slightly above threshold value. Concentration of DOC in fertilizer does not matter according to the Finnish Fertilizer regulation limit value (24/2011) therefore; furan sand can be used in composting.

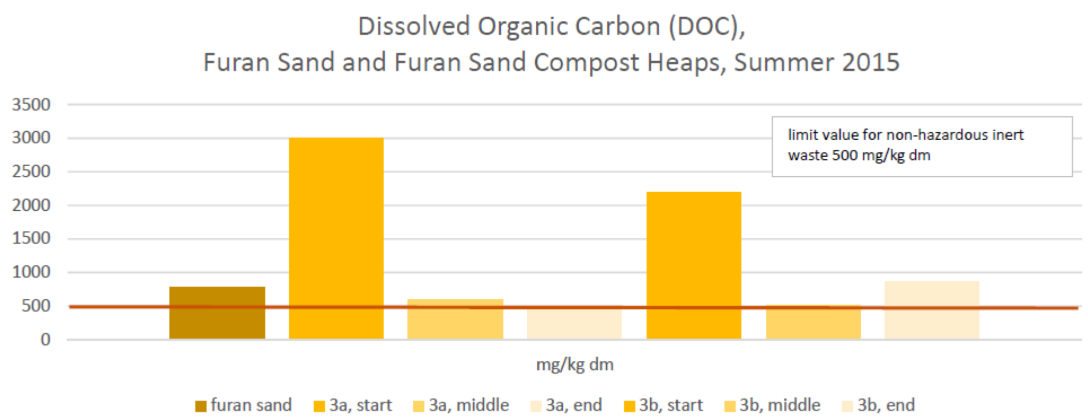

Figure 9: DOC value of furan sand and two different kind furan sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 10 illustrates the level of fluoride. The graphical representation shows that amount of fluoride elevated above the threshold value in green sand. The 1st, 2nd and 3rd phase test result for two different compost test heaps prepared from green sand demonstrated decrease in fluoride. This concludes that composting will decrease the elevated fluoride amount that was existed in green sand.

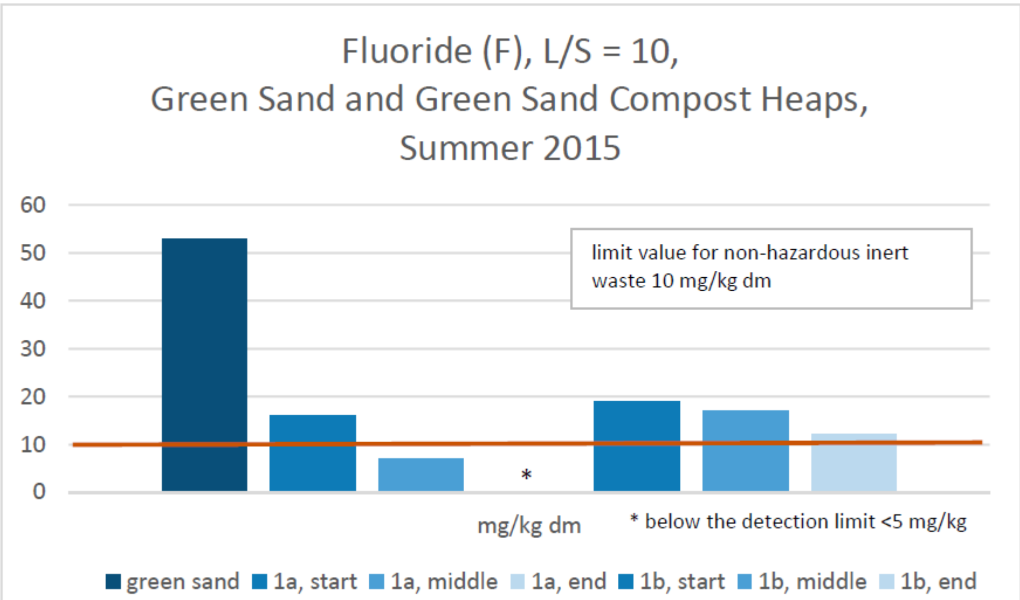

Figure 10: Fluoride value of green sand and two different kinds of green sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 11 illustrates the level of fluoride. The graphical representation shows that amount of fluoride elevated above the threshold value in alkaline phenolic sand. The 1st, 2nd and 3rd phase test results for two different compost test heaps prepared from alkaline phenolic sand demonstrated a decrease in fluoride. This concludes that composting will decrease the elevated fluoride amount that existed in alkaline phenolic sand.

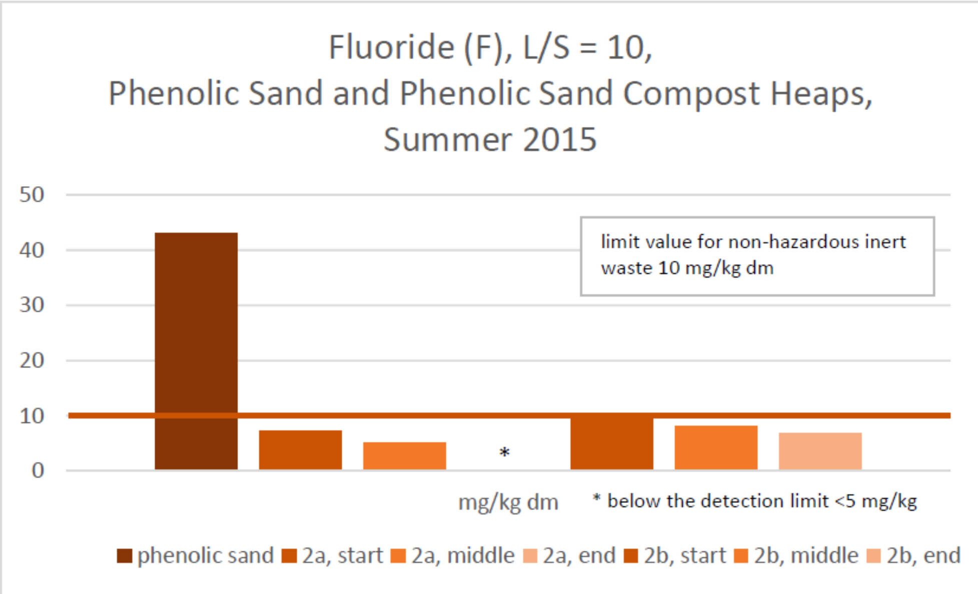

Figure 11: Fluoride value of alkaline phenolic sand and two different kinds of alkaline phenolic sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 12 illustrates the level of fluoride. The graphical representation shows that amount of fluoride is below the detection level in furan sand. The 1st and 2nd phase test results for two different compost test heaps prepared from furan sand demonstrated detection of fluoride and its increment. But 3rd phase test showed that fluoride amount in the compost below the detection limit. This concludes that amount of fluoride that might exist at the beginning of the composting will decrease below the detection limit later.

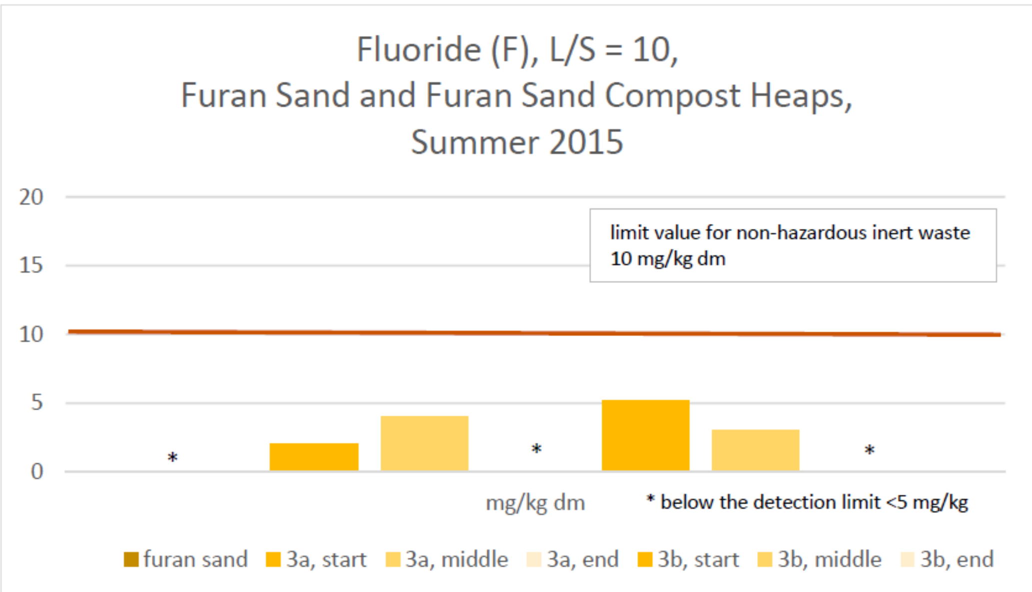

Figure 12: Fluoride value of furan sand and two different kinds of furan sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

The amount of fluoride concentration in green and phenolic sand sample is higher than the limit values set in Government decree of landfills (331/2013) for non-hazardous inert waste. This might be due to use of fluoride containing feeders in moulds. During the test fluoride concentration decreased that might be because of soluble nature of fluoride. Therefore, to decrease the amount of fluoride in surplus foundry sand, foundry could use fluoride free moulds or less fluoride containing feeders.

Figure 13 illustrates the level of phenol. The graphical representation shows that amount of phenol is below the detection level in green sand. The 1st phase test result for two different compost test heaps prepared from green sand demonstrated increase in phenol that might be due to presence of higher concentration of phenol in waste water sludge. The amount of phenol increased above threshold value for group “a” compost whereas for group “b”, it increased but remains below threshold value. The 2nd phase result illustrates phenol below detection limit for both composts. The final phase result showed phenol below detection limit for group “a” and group “b”. This concludes composting using green sand will not increase the phenol-index instead composting will help to eliminate the phenol present in waste water sludge.

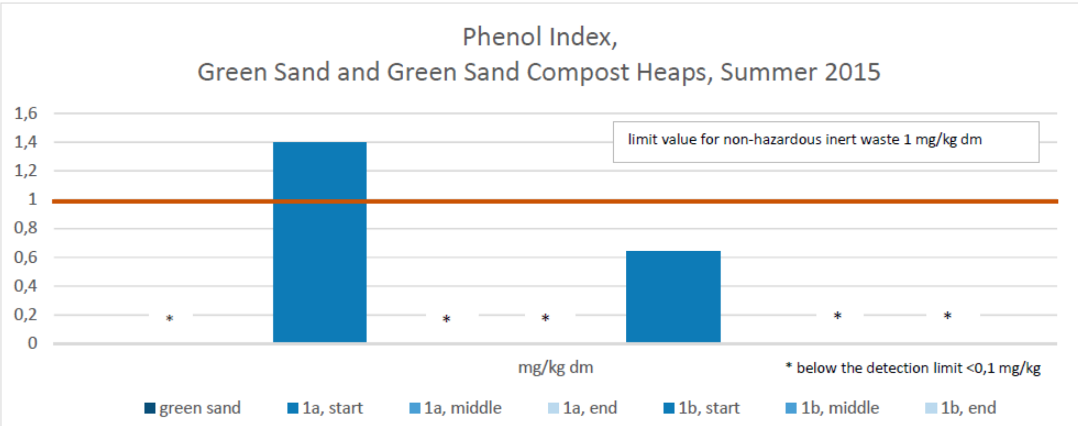

Figure 13: Phenol value of green sand and two different kinds of green sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 14 illustrates the level of phenol. The graphical representation shows that amount of phenol is elevated above the threshold in phenolic sand. The 1st phase test result for two different compost test heaps prepared from phenolic sand demonstrated increase in phenol for group “a” compost and decrease of phenol for group “b” compost. The later phase test result illustrated phenol below detection limit for both composts. This concludes composting will help to diminish phenol present in the alkaline phenol sand and waste water sludge.

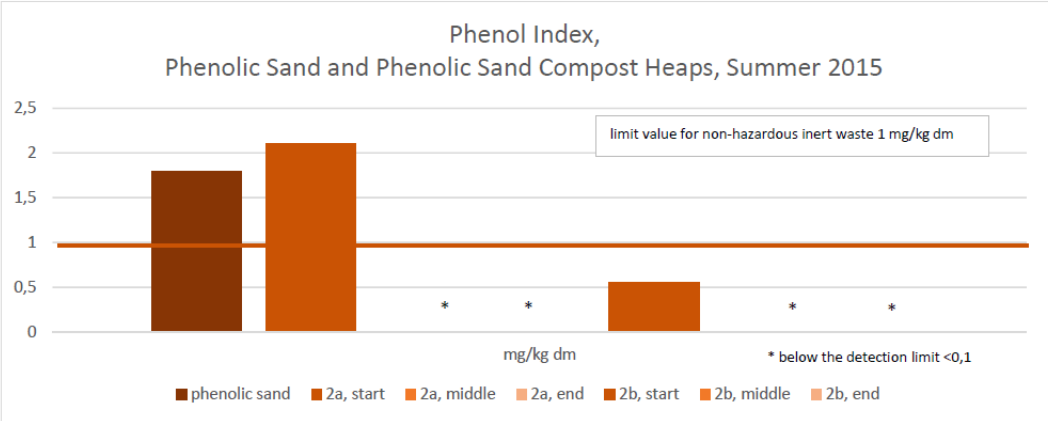

Figure 14: Phenol value of alkaline phenolic sand and two different kinds of alkaline phenolic sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 15 illustrates the level of phenol. The graphical representation shows that amount of phenol is below threshold value in furan sand. The 1st phase test result for two different compost test heaps prepared from furan sand demonstrated increase in phenol. The amount of phenol increases above threshold value for group “a” compost whereas for group “b” it increases but below threshold value. The later phase result illustrated phenol below detection limit for both composts. This concludes composting will help to eliminate the phenol from both furan sand and waste water sludge.

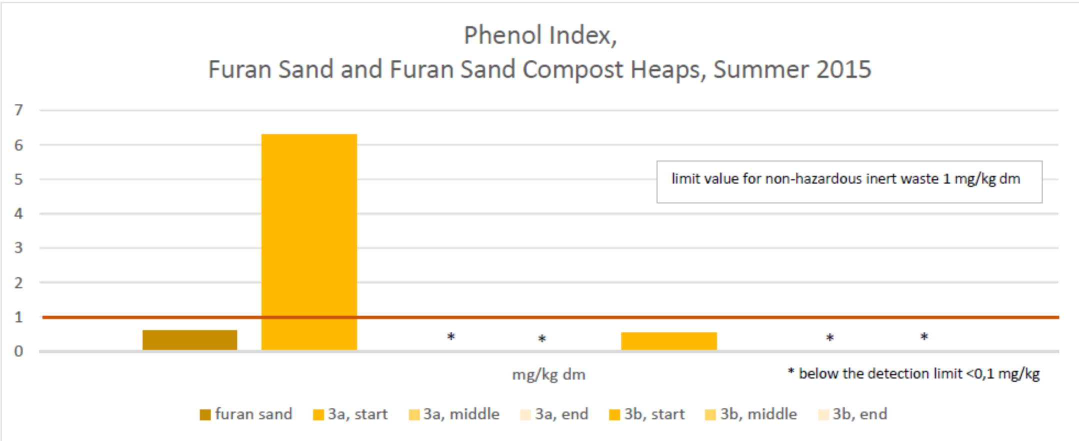

Figure 15: Phenol value of furan sand and two different kinds of furan sand compost (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Table 3.4 presents the beginning phase test result of surplus foundry sand and compost that evaluates the amount of BTEX, PAH, Chloride, PCB, petroleum hydrocarbons, sulphate and Total organic carbon (TOC). The result shows elevated BTEX noticed in Table 3.2 for furan sand above the threshold value is decreased during composting. The sulphate amount is higher in group “a” compost prepared using furan sand and waste water sludge. The amount of TOC is below threshold value for green and phenolic sand but is elevated for all compost, furan sand and sludge. The presence of hydrocarbons, E.coli and salmonella in the compost and waste water sludge were not analyzed in the initial phase test of waste water sludge and compost test heaps. The existence of PCB was not also analyzed for compost test heaps but for waste water sludge PCB was analyzed was under the detection limit.

Table 3.4 Initial phase test result of waste water sludge and compost that measures presences of BTEX, PAH chloride etc.(1a and 1b = green sand, 2a and 2b = phenol sand and 3a and 3b = furan sand composting test heaps) (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Beginning phase Analysis	unit	Sludge	1a	1b	2a	2b	3a	3b	Inert waste landfill threshold value (331/2013)	Fertilizer regulation limit value (24/2011)
BTEX	mg/kg	0.21	0.1	0.38	n.c	n.c.	1.39	4.01	6	-
16 EPA-PAH	mg/kg	0.6	0.32	0.41	0.5	0.4	0.28	n.c.	40	-
Chloride(Cl), L/S=10	mg/kg	210	150	92	120	110	120	110	800	-
Sulphate	mg/kg	3600	110	460	120	590	2000	830	1000	-
PCB	mg/kg	n.c.	#	#	#	#	#	#	1	-
Hydrocarbons C10-C40	mg/kg	#	#	#	#	#	#	#	500	-
Total organic carbon (TOC)	%	27.6	13.3	6.5	9.6	7.3	17.6	9	3	-
E.coli	cfu/g	#	#	#	#	#	#	#	-	1000 cfu/g
Salmonella	/25g	#	#	#	#	#	#	#	-	Neg./25g

n.c. = cannot be calculated, as the analysis of the results of all the individual compounds are below the detection limit
- = parameter does not have limit value
 # = not analyzed from the sample
Note: the values that exceed the limit values are highlighted with yellow color.

Table 3.5 presents the end phase test result of compost that evaluates the amount of BTEX, PAH, Chloride, PCB, petroleum hydrocarbons, sulphate, Total Organic Carbon (TOC) and microorganisms (E. coli and Salmonella). The result shows that BTEX, PAH and PCB in all compost sample were below the detection limit. The amount of TOC for all the compost sample increases above threshold value. The sulphate amount of all the composts is above threshold value except for composts 1b and 2b. The result of 1b and 2b compost illustrates sulphate below limit value. The result also shows that numbers of microorganisms are below the limit value.

Table 3.5 Final phase test result of compost that measures presence of BTEX, PAH chloride and microbes (LIFE13 ENV/FI/285 "Foundry sand", 2016).

End phase Analysis	unit	1a	1b	2a	2b	3a	3b	Inert waste landfill threshold value (331/2013)	Fertilizer regulation limit value
BTEX	mg/kg	n.c.	n.c.	n.c	n.c.	n.c	n.c	6	-
16 EPA-PAH	mg/kg	n.c	n.c	n.c	n.c	n.c	n.c.	40	-
Chloride(Cl), L/S=10	mg/kg	95	76	67	47	76	57	800	-
Sulphate	mg/kg	2500	880	1700	610	3100	2100	1000	-
PCB	mg/kg	n.c.	n.c	n.c.	n.c.	n.c.	n.c.	1	-
Hydrocarbons C10-C40	mg/kg	397	253	347	312	339	224	500	-
Total organic carbon (TOC)	%	5.9	4.4	5.0	3.3	7.0	5.3	3	-
E.coli	cfu/g	390	<1	10	12	1	48	-	1000 cfu/g
Salmonella	/25g	negative	negative	negative	negative	negative	negative	-	Neg./25g

n.c. = cannot be calculated, as the analysis of the results of all the individual compounds are below the detection limit
- = parameter does not have limit value
Note: the values that exceed the limit values are highlighted with yellow color.

Table 3.6 presents the test result of compost that evaluates water soluble metal in compost. The compost sample from the test heaps showed less water soluble metal concentration compared to the threshold value set for the non-hazardous inert waste and ordinary waste. There is no limit value set for the aluminum and iron was also analyzed. The existence of water soluble metal in waste water sludge was not analyzed.

Table 3.6 Water soluble metals in waste water sludge and compost test heaps (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Soluble metal L/S = 10	Unit	Waste water sludge	1a	1b	2a	2b	3a	3b	Non-Hazardous Inert waste landfill threshold value (331/2013)	Non-Hazardous ordinary waste landfill threshold value (331/2013
Aluminium (Al)	mg/kg dm	#	0.2	0.2	0.4	0.4	0.4	0.2	-	-
Antimony (Sb)	mg/kg dm	#	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.06	0.7
Arsenic (As)	mg/kg dm	#	0.02	0.03	0.03	0.02	0.03	0.03	0.5	2
Barium (Ba)	mg/kg dm	#	0.1	0.06	0.12	0.04	0.18	0.07	20	100
Cadmium(Cd)	mg/kg dm	#	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.04	1
Chromium (Cr)	mg/kg dm	#	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.5	10
Copper (Cu)	mg/kg dm	#	0.3	0.41	0.23	0.3	0.19	0.25	2	50
Lead (Pb)	mg/kg dm	#	0.04	0.07	0.04	0.29	0.09	0.09	0.5	10
Molybdenum (Mo)	mg/kg dm	#	0.0.4	0.04	0.05	0.04	0.03	0.06	0.5	10
Nickel (Ni)	mg/kg dm	#	0.10	0.08	0.07	0.07	0.07	0.1	0.4	10
Iron (Fe)	mg/kg dm	#	1.2	1.2	1.4	2.2	1.5	3.3	-	-
Selenium (Se)	mg/kg dm	#	0.08	<0.01	0.08	<0.01	<0.01	<0.01	0.1	0.5
Zinc (Zn)	mg/kg dm	#	0.4	0.3	0.3	0.2	1	0.4	4	50
Mercury (Hg)	mg/kg dm	#	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.01	0.2

 # = There is no analysis of the sample
- = There is no limit value for the parameter

Table 3.7 illustrates the test result of compost that evaluates total metal concentration in compost test heaps and waste water sludge. The compost sample from the test heaps and waste water sludge sample showed lower water soluble metal concentration compared to the threshold value set for Finnish fertilizer regulation limit value (24/2011). There is no limit value set for the aluminum, iron, antimony, molybdenum, selenium and barium were also analyzed.

Table 3.7 Total metal concentrations in waste water sludge and compost test heaps (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Total metal Concentration	**Unit**	**Waste water Sludge**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**	**Fertilizer regulation limit value (24/2011)**
Aluminium (Al)	mg/kg dm	2000	5800	6200	2200	2100	2800	1600	-
Antimony (Sb)	mg/kg dm	<1	<1	<1	<1	<1	<1	<1	-
Arsenic (As)	mg/kg dm	3	3.6	2.9	2	1.9	2.6	1.9	25
Barium (Ba)	mg/kg dm	78	100	84	52	45	64	53	-
Cadmium(Cd)	mg/kg dm	0.4	3	<0.2	<0.2	<0.2	<0.2	<0.2	1.5
Chromium (Cr)	mg/kg dm	13	39	34	18	21	18	21	300
Copper (Cu)	mg/kg dm	72	120	100	43	31	49	35	600
Lead (Pb)	mg/kg dm	11	11	8	6	5	9	9	100
Molybdenum (Mo)	mg/kg dm	3	<2	<2	<2	<2	<2	<2	-
Nickel (Ni)	mg/kg dm	14	27	22	15	15	14	13	100
Iron (Fe)	mg/kg dm	71000	61000	35000	37000	24000	45000	33000	-
Selenium (Se)	mg/kg dm	<1	<1	<1	<1	<1	<1	<1	-
Zinc (Zn)	mg/kg dm	230	260	200	140	100	160	120	1500
Mercury (Hg)	mg/kg dm	0.09	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1

- = *There is no limit value for the parameter*

Table 3.8 illustrates emission from the compost to the environment. The test result from initial, during and end phase test is presented. To find out the effluent made by the compost the sewage test was conducted. The sewage test conducted present the information about different emissions that the waste water from the compost test heaps contains. The emissions contained are heavy metal, PAH, bacteria, phenol etc. The concentration of effluents was below the limit value set in Ekokem guide 1/09.

Table 3.8 Initial sewage test to evaluate metal contain, pH, phenol-index, fluoride, PAH, bacteria etc. (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Analysis	**unit**	**Start**	**Middle**	**End**	**Threshold value from Ekokem guide 1/09**
Phenol-index	mg/l	<0.05	<0.008	<0.05	10
Fluoride	mg/l	<0.3	<0.3	<0.3	-
Polycyclic Aromatic Hydrocarbons (PAH)	mg/l	0.002	<0.0001	0.00003	0.05
BTEX	mg/l	<0.001	<0.001*	<0.001	3
Aluminum (Al)	mg/l	0.2	0.07	0.2	-
Mercury (Hg)	mg/l	<0.0005	<0.0001	<0.0005	0.01
Cadmium (Cd)	mg/l	<0.001	<0.0002	<0.001	0.01
Chromium (Cr)	mg/l	<0.005	<0.001	<0.005	1
Copper (Cu)	mg/l	0.034	0.014	0.029	2
Lead (Pb)	mg/l	<0.005	<0.001	<0.005	0.5
Nickel (Ni)	mg/l	0.013	0.006	0.006	0.5
Iron (Fe)	mg/l	2.47	2.7	0.82	-
Zinc (Zn)	mg/l	0.05	0.02	0.02	3
Total nitrogen (N)	mg/l	50	5.8	26	-
Ammonium (NH_3)	mg/l	70	2.7	0.49	-
Total phosphorus (P)	mg/l	2.0	0.55	0.31	-
pH	mg/l	7.6	7.3	7.4	6.0-11.0
BOD7	mg/l	30	7.4	4	-
CODcr	mg/l	310	86	100	-
Solid Matter	mg/l	26	7.9	8	500
Electrical conductivity	µS/cm	540	270	490	-
thermotolerant coliform Bacteria	cfu/100ml	9300	48	<1	-

**BTEX results are indicative because of long period of time between the sampling and analyzing*

-= *no limit value for parameter*

From all the test results shown in section 3.1, the following conclusion can be drawn:
The concentration of the water soluble metal, total concentration of heavy metals that exists in surplus foundry sand samples, waste water sludge and composting test heaps were below the threshold values set for non-hazardous inert waste in Government decree of landfills (331/2013) and limit value set in Decree of the ministry of Agriculture and forestry on fertiliser Products (24/2011). The composting experiment showed that surplus foundry sand

that would have been dumped in landfill contains fluoride, phenol and BTEX. The amount of BTEX in furan sand sample exceeded the limit value. These harmful components disappear during composting process. In case of other parameters and compounds almost all of the concentration was below the limit value set in Decree of the ministry of Agriculture and forestry on fertiliser Products (24/2011) and Government decree of landfills (331/2013); except for sulphate and total organic carbon (TOC) that exceeded the limit values of non-hazardous inert waste. There are no limit values of sulphate and TOC mentioned in fertilizer products so the concentrations would not cause any problem utilizing the end-product in agriculture. The experiment conducted in summer 2015 was the first phase of this project where reuse possibility of SFS in composting was tested with other compostable organic materials such as horse manure, sludge and wood chips. From experiment, it is studied that sludge increases the harmful substances levels of compost material such as phenol, concentration of heavy metals and DOC. But phenol disappears during composting and the other substances are below the limits and are not an issue in using in agricultural sector. This experiment also cleared the doubt that foundry sand cannot be used without composting directly as a mixing substance for sludge. If sludge is allowed to mix with SFS for couple of months, it forms sludge compost that can be used in agricultural sector. The emissions test also proved that there will not be any harmful materials that emit above the limit value that will adversely affect human and animal health and environment.

3.2 Composting of foundry sands

The composting test was performed in Koukkujärvi compost plant in summer 2015. Six compost test heaps were prepared in Koukkujärvi under the supervision of MeehaniteTechnology Ltd and Tampere Regional Solid Waste Management Ltd (Pirkanmaan Jätehuolto Oy). In the experiment, the most typically used foundry sands for example green sand, alkaline phenolic sand and furan sand were studied. Dust and slag that produced in the foundries as waste were not included in experiment due to the doubt that slag and dust might have heavy metals. In Finland, three different foundries were selected to get three different sands. They are:

- Iron foundry that uses phenol sand system
- Iron foundry that uses green sand system
- Aluminium Foundry that uses furan sand system

The presence of heavy metal was studied prior to the surplus foundry sand mixed into the test compost windrows as shown in Table 3.1 and 3.2. For the study of compost, two different groups, i.e., A and B of all three types of the surplus foundry sand were prepared and given names 1a and 1b for green sand heaps 2a and 2b for alkaline phenolic sand heaps and 3a and 3b for furan sand heaps. Figure 16, 17 and 18 show the types of surplus foundry sand used during composting tests. The size of the test heap prepared was about 20 to 24 tons. The test heaps prepared used foundry sand and other compostable material such as wood chips, horse manure and waste water sludge.

Six test heaps were prepared as shown below:

- Three test heaps 1a, 2a, 3a that contained green, phenol and furan sands used 20% of respective sands.
- Three test heaps 1b, 2b, 3b that contained green, phenol and furan sands used 30% of respective sands.

Figure 16: Green sand, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 17: Alkaline phenolic sand, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 18: Furan sand, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

The composts heaps were prepared mixing weighted surplus foundry sand and composting materials. Since the temperature plays vital roles in composting, number of temperature sensors were placed in different parts of the compost heaps to study the temperature and condition of the compost. Figure 19 shows temperature changes in the different depths of the heaps. The 6 compost heaps prepared from the three different kinds of sand look similar. It is therefore, in order to prevent any confusion; they were given name as presented in Figure 20.

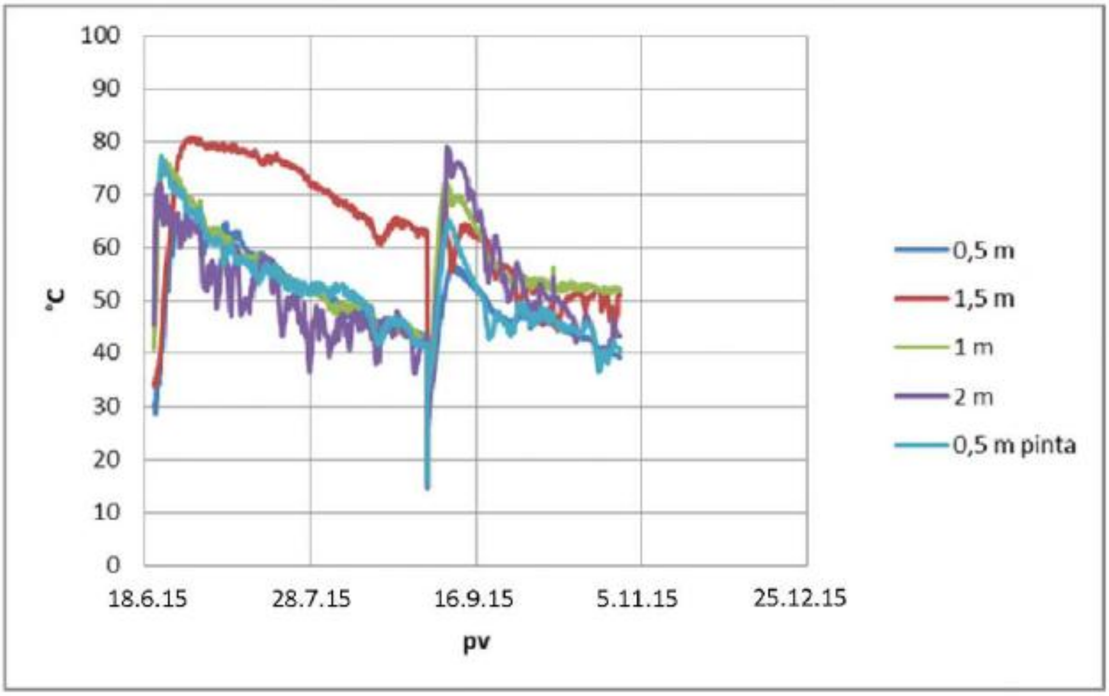

Figure 19: Temperature changes in different depth of green sand compost test heap, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 20: Six composting test heaps with label, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Since the composting process is an aerobic process and is exposed to the rain and environment, there is possibility that various constituents present are leached. For this, emission test set up was prepared as shown in Figure 21 a) and 21 b), in order to measure the possible emissions that could happen during the composting process. Waste waters of the test heaps were collected and analyzed during the test to evaluate the potential effluents from composting test. The composting process evolution was continuously followed and controlled by measurable indicators i.e. temperature and pH. Test sample from each test heap was collected as illustrate in Figure 22 in the beginning, during and in the end of the test period. After completing the necessary setup, the heaps were left to compost. Mixing of heaps and measuring of temperature and emissions was done every now and then. The test heaps took approximately 4.5 months for composting. Figure 23 illustrates the composted heaps.

a) b)

Figure 21: a) Emission measurement and b) Effluent measurement, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 22: Sampling procedure from each test heaps, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

Figure 23: Composted test heaps in the end of composting test, (LIFE13 ENV/FI/285 "Foundry sand", 2016).

4. Discussion

4.1 Acceptance criteria for the utilization of foundry sand in composting

The main objective of this research was to find the harmful components in the most commonly used foundry sands in Finland and compost made from those sand. The acceptance criteria used in this research assists in preventing pollution of soil and ground surface water. The research was performed comparing the harmful compound present in the sand and compost with the Finnish standard inert landfills threshold value mentioned in government regulation on landfills (331/2013). The recommendation in this thesis for using surplus foundry sand in compost are given on the basis of these results. Table 4.1 shows different threshold values used in Finland that directly and indirectly belong to the soil use. As mentioned earlier from literature review in 1.5.1, Finnish legislation is not familiar with the term product development by which the materials could bypass the application of the waste law that seems controversial. Because Finland has legislation called Mara-asetus (591/2006) that by passes the certain industrial waste. But this legislation is as stricter as inert waste landfills threshold value. This Mara-asetus legislation could have been less stringent so that foundries would develop more interest in reusing surplus foundry sand in composting than dumping in landfills.

Table 4.1 Different threshold value used in Finland

Substance (symbol) L/S = 10	Finnish soil contamination and remediation (214/2007) threshold value mg/kg	Ministry of Agriculture and Forestry Decree on fertilizer products(24/2011)	Mara-Asetus threshold (591/2006) value mg/kg	Hazardous waste Landfills (kaatopaikka (331/2013)) Threshold value mg/kg	Conventional waste to Landfills (kaatopaikka (331/2013)) Threshold value mg/kg	Inert waste Landfills (kaatopaikka (331/2013)) Threshold value mg/kg
Antimony (Sb)	2	-	0.06	5	0.7	0.06
Arsenic (As)	5	25	0.5	25	2	0.5
Barium (Ba)	-	-	20	300	100	20
Mercury (Hg)	0.5	1.0	0.01	2	0.2	0.01
Cadmium(Cd)	1	1.5	0.02	5	1	0.04
Cobalt (Co)	20	-	-	-	-	-
Chrome (Cr)	100	300	0.5	70	10	0.5
Copper (Cu)	100	600	2	100	50	2
Molybdenum	-	-	0.5	30	10	0.5
Lead (Pb)	60	100	0.5	50	10	0.5
Nickel (Ni)	50	100	0.4	40	10	0.4
Zinc (Zn)	200	1500	4	200	50	4
Vanadium (V)	100	-	2	-	-	-
Selenium (Se)	-	-	0.1	7	0.5	0.1
PAH	15	-	-	1000	-	40
Fluoride (F^-)	-	-	10	500	150	10
Chloride (Cl^-)	-	-	800	25000	15000	800
Sulphate(SO_4^{2-}	-	-	1000	50000	20000	1000
DOC	-	-	-	1000	800	500
Phenol index	-	-	-	-	-	1
PCB	0.1	-	-	-	50	1
TOC	-	-	-	6%	5%	3%

4.2 Development of the quality control system for surplus foundry sand for reuse in composting

This thesis also has the general proposal for guideline that is necessary to maintain the quality control of the surplus foundry sand produced which might help for certification of SFS for composting. According to the provision of Finnish Environment Protection act (527/2014) and Waste act (646/2011), the foundries are required to follow Government Decree of landfills (331/2013) to ensure the recovery of the waste before dumping surplus foundry sand to the landfills. The sampling and methods to prepare samples are performed in accordance with standards Tests for general properties of aggregates; Part 1: Methods for sampling and Part 2: Methods for reducing laboratory samples (SFS-EN 932-1 and SFS-EN 932-2) and also draft standard prEN 14899. Samples are being taken silo and different test methods which are described under Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with high content and with particle size below 4 mm (with or without size reduction) (SFS-EN 12457-3) are conducted. This shows that Finnish foundries are already performing the quality control investigations that determine and investigate the harmful substances present in the waste foundry sand.

In order to ensure the quality of the system, it is necessary to define the quality of the surplus foundry sand every year. This would be good practice to monitor the fluctuation in the quality of the surplus foundry sand delivered for composting purpose. This quality control is proposed in proposal attached in Appendix 2 for the Finnish foundries on the basis of government regulation on landfills (331/2013).

5. Conclusions

5.1 Legislation and authorization

The environment protection act (527/2014) was implemented. The required condition to use surplus foundry sand in composting and criteria for obtaining the permit is same in the environment permit act. The endproduct of composting should fulfill the criteria set by fertiliser Products (24/2011) and inert waste landfills regulation (331/2013).

The permit granting process is tough and can discourage foundry and composter. Therefore, to increase the probability of simplifying, the environment process which hinders the reuse possibility of surplus foundry sand in composting was described in proposal of this thesis.

It is quite necessary that foundries do detailed investigation of their material to fulfill the environmental and technical standards set by the legislation. Since the quality control system in foundries monitor the fluctuation in the quality of the surplus foundry sand and grant the standard limits. It is required to pay a proper attention to the quality control system. The quality control data with other necessary research data would help to get environment permit for composter.

5.2 Quality Control

In case of waste or by product from the industries, the quality control plays a vital role to make it acceptable for utilizing in composting, substituting the traditional materials. The environmental properties of surplus foundry sand have to be studied based on the proper quality control system. According to the general environmental law, the industry and commercial organization are responsible for their own waste generated. Therefore, it is necessary in many countries to include a plan and schemes for the environmental approval of industries and also to present the report annually on the performance indicators. In Finland, in case of surplus foundry sand dumping in landfills, the quality control assurance is done on the basis of Government Decree on landfills (331/2013) concerning "Waste material may not endanger surface or ground water quality and may not react or no harmful substances can dissolve from it." Flow chart in Figure 24 demonstrates environmental qualification determining steps. As shown in flow chart the sample collected from free falling stream in a foundry should be under the size of 4 mm is accordance with standards Tests for general properties of aggregates; Part 1: Methods for sampling and Part 2: Methods for reducing laboratory samples (SFS-EN 932-1 and SFS-EN 932-2) as well as draft standard

Characterization of waste sampling of waste materials framework for the preparation and application of a sampling plan (prEN 14899). And the collected sample size is 1 kg. The detection of the heavy metal is performed using EN standard: Characterization of waste. Digestion for subsequent determination of aqua regia soluble portion of elements in waste (prEN 13657) or EN standard: Characterization of waste. Microwave assisted digestion with hydrofluoric, nitric and hydrochloric acid mixture for subsequent determination of elements in waste (prEN 13656) test. PAH and PAB are on the basis of Nordtest. The leaching of the harmful compounds is evaluated by L/S relation 10 following test Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with high content and with particle size below 4 mm (with or without size reduction) (SFS-EN 12457-3) or using column test (VTT, 2000).

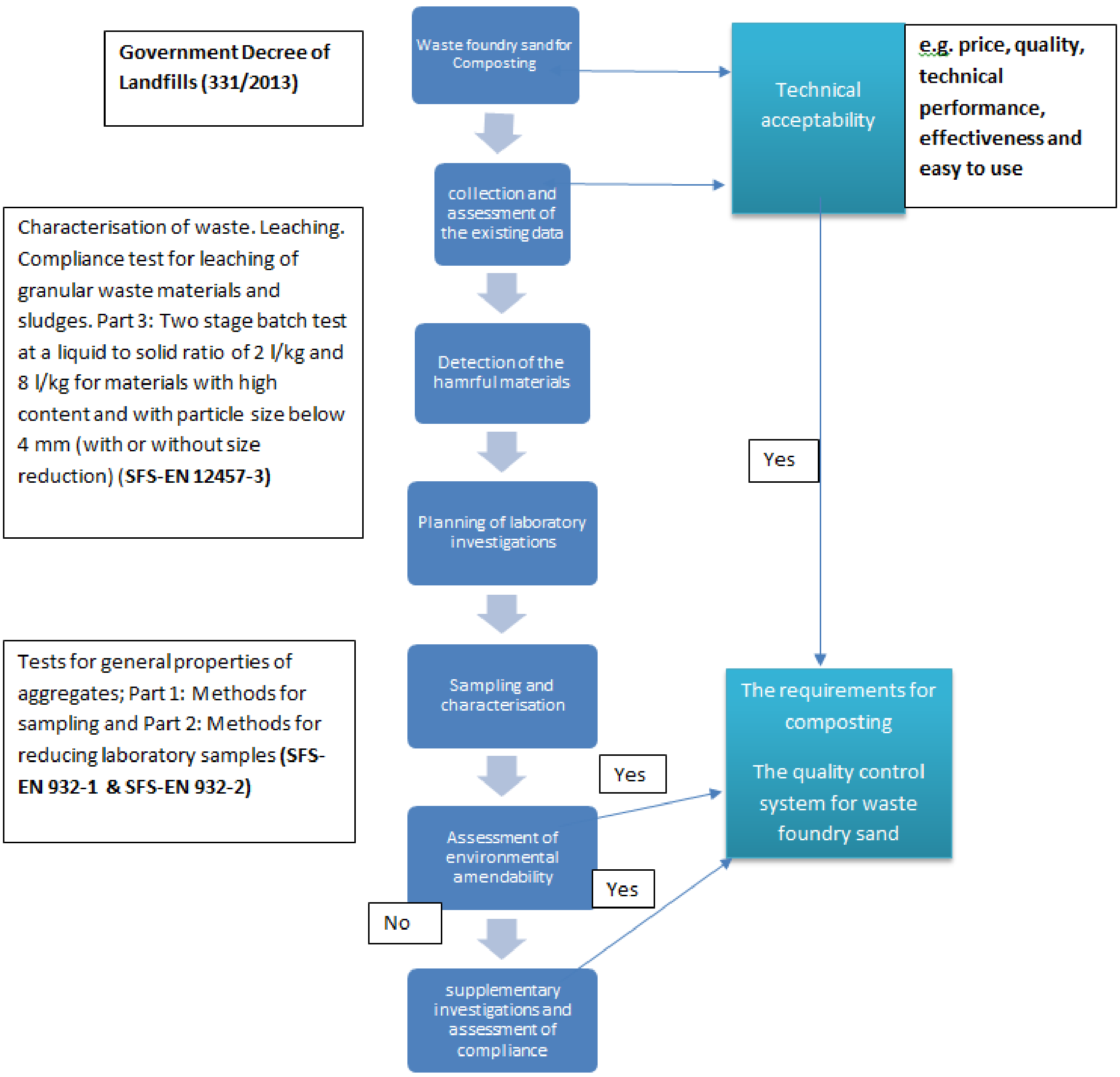

Figure 24: Main phase of investigation for environmental assessment of waste. (VTT, 2000).

5.3 Summary

The composting experiment was performed in summer 2015, will be conducted until 2017 in two phases each year. The experiments were done in Koukkujärvi waste treatment center, Finland and in Spain by Tecnalia Research & Innovation Foundry association. The conclusion drawn is based on test results published by project partners Meehanite Technology Ltd, AX-LVI Consulting Ltd, Eurofins Viljavuuspalvelu Ltd carried out the biological and chemical analyses from the tests.

The environmental properties of the compost prepared from the surplus foundry sand and other compostable materials (sludge, horse manure and wood chips) were studied. Various leaching tests, screening tests were performed as described in the Finnish regulations. The results were compared to the threshold values set for inert waste landfills regulation and fertilizer regulations. The results for heavy metals contents were under the standards set, fertility test was positive and maturity of the composts were stabilized and adequate. From experiment, it came to a conclusion that surplus foundry sand can be cleaned by composting method from organic compounds (e.g. PAH, phenol, petroleum hydrocarbons, BTEX) and fluoride that might retain in the SFS, by composting it together with compostable materials. Therefore, leaching of these harmful substances in environmental resources is possible to control. Since less research has been conducted on the reuse possibility of foundry sand in composting, this experiment has demonstrated innovative composting method for cleaning the surplus foundry sands. Further studies in compostable material that can be used with surplus foundry sand will be made. The effect due to the change in temperature will also be studied in this research. As Finland's new waste act law (646/2011) that will be implemented from beginning of 2016 has prohibited dumping of organic waste in landfills. This work will help to solve the problem of managing the organic waste coming from households too. This would on the other hand, solve the problem that exists in small and densely populated areas due to limited landfill capacity (www.yle.fi). Methane, which is one of the worst greenhouse gases that promotes global warming and can be produced from dumping of organic waste, will be controlled to some extent too. After discussion with authorized personnel about the quality control process mentioned in Table 2.2.1, quality control process was considered to be too heavy to handle. Therefore, formalities are being performed and discussions with authorities are being done to make quality control process easier by adapting Finnish government regulation on landfills (331/2013). According to which, the surplus foundry sand can be analysed at least once a year. Authorities are reconsidering to include surplus foundry sand in Mara-asetus regulation which could by pass certain potential waste.

The quality control system proposal for reuse possibility of surplus foundry sand in composting have been made for the EU commission Environment - Life Programme 2013 and for affiliation of Finnish regional and local authorities. The proposal contains the quality control system that would meet the quality assurance standard of inert waste landfills regulation (331/2013). The proposal prepared will help Finnish foundries to monitor the fluctuation in the quality of their surplus foundry sand. This proposal will help to create the guideline for Finnish foundries after discussion with concerned authorities.

The main motive of this research is to slow down the rate of virgin soil extraction from natural resources. This would help environment to remain clean and green.

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Appendix 1

ANNEX II

MINIMUM CONTENTS OF SECONDARY NUTRIENTS AND MICRO-NUTRIENTS IN FERTILISER PRODUCTS AS WELL AS CHELATES, COMPLEXING AGENTS AND OTHER ORGANIC MATERIALS PERMITTED TO BE ADDED TO FERTILISERS

A. MINIMUM CONTENTS OF SECONDARY NUTRIENTS AND MICRO-NUTRIENTS

Table 1. Minimum content of secondary nutrients which must be declared for fertilisers.

Secondary nutrient	Content in fertilisers as a percentage by weight
Calcium (Ca)	1.4
Magnesium (Mg)	0.5
Sodium (Na)	2.2
Sulphur (S)	1.0

If the minimum content of the water-soluble ingredients of magnesium (Mg), sodium (Na) or sulphur (S) is a quarter of its total content, the water-soluble content is declared in addition to the total content. For water-soluble ingredients, only their water-soluble content is declared. For calcium, only the water-soluble content is declared.

Table 2. Minimum content of secondary nutrients which may be declared for soil improvers. The measure used is mg/kg of dry matter but the content per fresh weight or volume may also be declared; in liquid fertiliser products as mg/l.

Secondary nutrient	Content as mg/kg or mg/l
Calcium (Ca)	500
Magnesium (Mg)	20
Sulphur (S)	20

The minimum content of micro-nutrients in fertilisers must be declared as a percentage by weight of dry matter or of total weight, in liming materials as a percentage by weight of dry matter and in other fertiliser products as mg/kg of dry matter (the content may also be declared per fresh weight), in liquid fertiliser products as mg/l.

Table 3 A. Minimum content of micro-nutrients declared for fertiliser products spread on growing media.

Micro-nutrient	Content as a percentage by weight
Boron (B)	0.01
Cobalt (Co)	0.002
Copper (Cu)	0.002
Iron (Fe)	0.02
Manganese (Mn)	0.01
Molybdenum (Mo)	0.001
Zinc (Zn)	0.002
Selenium (Se)	0.001

Table 3 B. Minimum content of micro-nutrients declared for fertiliser products used as leaf spray.

Micro-nutrient	Content as a percentage by weight
Boron (B)	0.01
Cobalt (Co)	0.002
Copper (Cu)	0.002
Iron (Fe)	0.02
Manganese (Mn)	0.01
Molybdenum (Mo)	0.001
Zinc (Zn)	0.002
Selenium (Se)	0.001

B. PATHOGENS AND OTHER MICRO ORGANISMS

Maximum permitted amounts of pathogenic or disease indicator micro organisms are shown in Tables 2 and 3.

Table 2. Maximum permitted amounts of pathogens/indicator organisms in fertiliser products.

Pathogen/indicator	Maximum amount
Salmonella	Not found in a sample of 25 grams
Escherichia coli	Less than 1000 CFU/g and less than 100 CFU/g in growing media intended for commercial greenhouse production where edible plant parts are in direct contact with the growing media
Root rot fungus (for instance, *Fusarium*; found using a culture test)	Not found in growing media used in seedling production

Appendix 2

General Proposal for Guideline

Waste foundry sands - Quality control system Guideline for reuse possibility in composting

The proposal is designed to assist foundries in setting quality control system criteria to control the quality of the waste foundry sand to make it feasible for re-use in manufacturing compost preventing any risk to environment, human and natural resources in accordance with waste management act.

The proposal for development of quality control system for waste foundry sand was funded by EU Commission Environment - Life Programme 2013. It was developed by Aalto University in consultation with MeehaniteTechnology Ltd, AX-LVI Consulting Ltd, EU commission Environment - Life Programme 2013, foundries and authorities. The proposal for development of the quality control system for waste foundry sand is applicable for Finnish foundries in Finland.

Contents

1. Development of the quality control system for waste foundry sand

1.1 Introduction

The proposal for development of the quality control system of waste foundry sand for compost use has been developed to provide clear and existing advice to foundries to ensure the consistency in quality of the waste sand produced in foundries.

This proposal has been prepared to create clear expectations for foundries, compost manufacturers, end users/potential users and local authorities. The proposal suggests techniques to foundries in assessing the risks of environmental harm from waste foundry sand as well as in complying with their environmental duty as per environmental relevant industrial waste management activity (646/2011). The proposal is simple and intended to focus in shorter development of quality assessment timeframes.

1.2 Purpose of Proposal

The main goal of the proposal is to create the guideline that will focus on eco-efficient product development. The proposal especially focuses on development of process that can control the quality of waste sands produced in foundries to increase confidence and for using it in composting purposes.

The aims of this proposal are to:

- Promote waste foundry sand especially, green sand, furan sand, and alkaline phenolic sand as substitute material to virgin sand in production of compost.
- Introduce methods and system to Finnish foundries for waste foundry sand qualification that produce sufficient information on the properties of waste foundry sand that would decrease the long and tedious permit granting process.
- Providing the potential end-users i.e., compost manufacturers confidence, and to find reliable and steady market for reuse of waste foundry sand in composting and other designated purposes.
- Promoting clean and green product development that protects human health, environment and natural resources.

1.3 Scope of Proposal

The proposal applies to the foundries that produce waste as foundry sand regulated under Finnish government decree on waste (179/2012). It is mainly targeted to the Finnish foundries that use foundry sand such as green sand, furan sand and alkaline phenolic sand as their raw material and to the Finnish compost manufacturers that use waste foundry sand as their raw materials.

1.4 Waste foundry sand

The waste foundry sand may contain metals from casting, core and mould materials that might include partially degraded organic and inorganic binders. It may even contain some leachable contaminants, such as heavy metals, phenols, DOCs (dissolved organic material), fluoride that could have been absorbed by sand during moulding and casting processes. The existence of the heavy metals for example cadmium, lead, copper, nickel, arsenic and zinc that could have generated during non-ferrous casting process, phenols that might have formed during high-temperature thermal decomposition and rearrangement of organic binder are a matter of huge concern for its reuse purpose in composting. The presence of phenols in waste foundry sand may discharge phenols into surface and ground water supplies due to their leachable nature. Dust, slag and fresh moulds and cores that are produced in foundries might have higher concentration of heavy metals and higher potential of leachability of organic materials. Therefore, surplus foundry sand that has not been in contact with such materials is requested for composting purposes. The Finnish government decree on waste (179/2012) considers waste foundry sand produced from casting of ferrous and non-ferrous materials as hazardous waste and need to establish control system for potential phenol, heavy metal, DOCs and fluoride discharges. The Finnish regulation on landfills (331/2013) threshold values that are used to assess concentration of harmful material in soil while dumping waste foundry sand in landfills are taken as reference for quality control and is illustrated in Table 1.

Table 1: The different threshold values used to assess harmful substances in soil.

Substance (symbol)	**Hazardous waste Landfills (kaatopaikka (331/2013)) Threshold value mg/kg**	**Conventional waste to Landfills (kaatopaikka (331/2013)) Threshold value mg/kg**	**Inert waste Landfills (kaatopaikka (331/2013)) Threshold value mg/kg**
Antimony (Sb)	5	0.7	0.06
Arsenic (As)	25	2	0.5
Barium (Ba)	300	100	20
Mercury (Hg)	2	0.2	0.01
Cadmium(Cd)	5	1	0.04
Cobalt (Co)			
Chrome (Cr)	70	10	0.5
Copper (Cu)	100	50	2
Molybdenum (MO)	30	10	0.5
Lead (Pb)	50	10	0.5
Nickel (Ni)	40	10	0.4
Zinc (Zn)	200	50	4
Vanadium (V)			
Selenium (Se)	7	0.5	0.1
PAH	1000		40
Fluoride (F^-)	500	150	10
Chloride (Cl^-)	25000	15000	800
Sulfate(SO_4^{2-})	50000	20000	1000
DOC	1000	800	500
Phenol index			1
PCB		50	1
TOC	6%	5%	3%

1.5 Producing quality waste foundry sand and evidence for composting

The description of the main stages and control mechanisms used for quality control system of waste foundry sand are shown in Figure 1 and Figure 2 respectively. The main stages signify all the essential steps that are similar to the process required to be performed by foundry before dumping waste foundry sand in landfills and steps essential to get environmental permit.

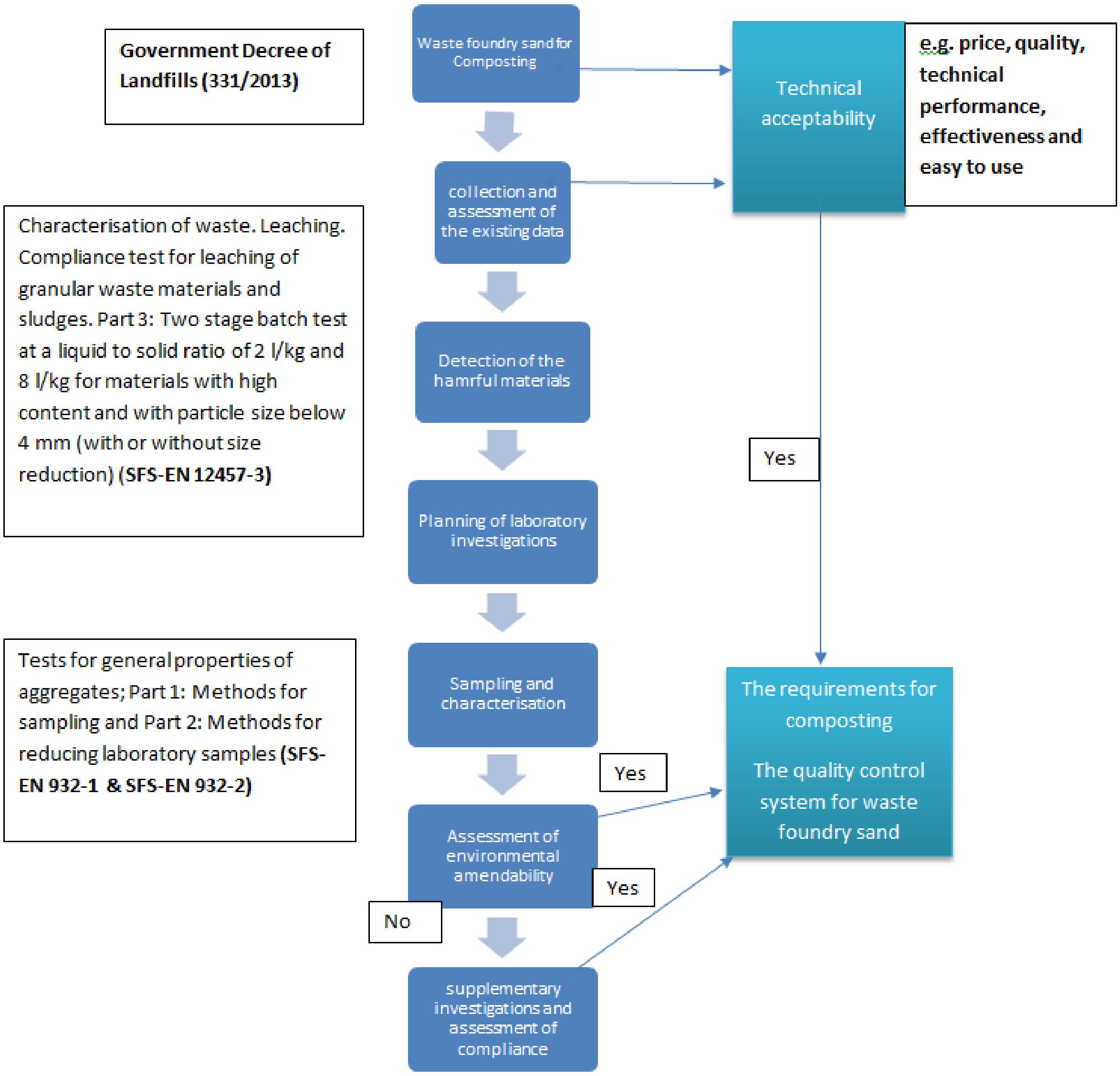

Figure 1: The outline of main stages before quality control mechanism (VTT, 2000).

According to the Finnish government regulation on landfills (331/2013) section 20 compliance testing, the waste batches might need to be tested to monitor the quality of the waste. Therefore, foundry may require testing surplus foundry sand to obtain the data related to basic characterization of the composition and the solubility characteristics of surplus foundry sand as mentioned in section 25 of government regulation on landfills (331/2013). Since waste foundry sand in foundry is regularly generated waste it is subjected to compliance testing as mentioned in section 19, and does not require regular testing of waste batches. The compliance testing i.e. mentioned in section 20 shall be repeated at least once a year to show that surplus foundry sand produced meets the threshold values set. The foundry should keep record of compliance testing at least for three month from the date of receipt since these documents are useful for composter to get environmental permit for composting.

The environmental permits for the use of surplus foundry sand in composting are based on 28.2 section 4 of the Environment protection act. The use of the guideline prepared from this proposal does not affect the requirement for composter to hold an environment permit because permit that is required for the use of surplus foundry sand in composting is same as for discarded materials mentioned in Waste Law, section 42 (Mroueh, 2002).

While applying for environmental permit, a composter may need to check the amount of surplus foundry sand it is composting. If the amount of surplus foundry sand to be composted exceeds 5000 tons, the composter may get permit from Regional State Administrative Agencies (RSAA) rather than local authorities (Mroueh, 2002).

In this applying process, the composter may need to provide previously conducted characterization report of surplus foundry sand along with quality control data that conducted by foundry that would provide adequate information to environmental authorities about environmental compliance, such as:

- Comparison of harmful components with acceptance criteria
- Sampling methods and test methods used for evaluation, results of comparison with standards and authorized person
- Results of risk assessment
- Other potential harmful materials to the environment and relevant research document
- Quality control of the environmental compliance research

As mentioned in the Finnish environment Protection act (527/2014), the user of the waste foundry sand may need to present the record of quality, amount of origin, depositing location and technical implementation of waste foundry sand in composting for getting environmental permit (Mroueh, 2002).

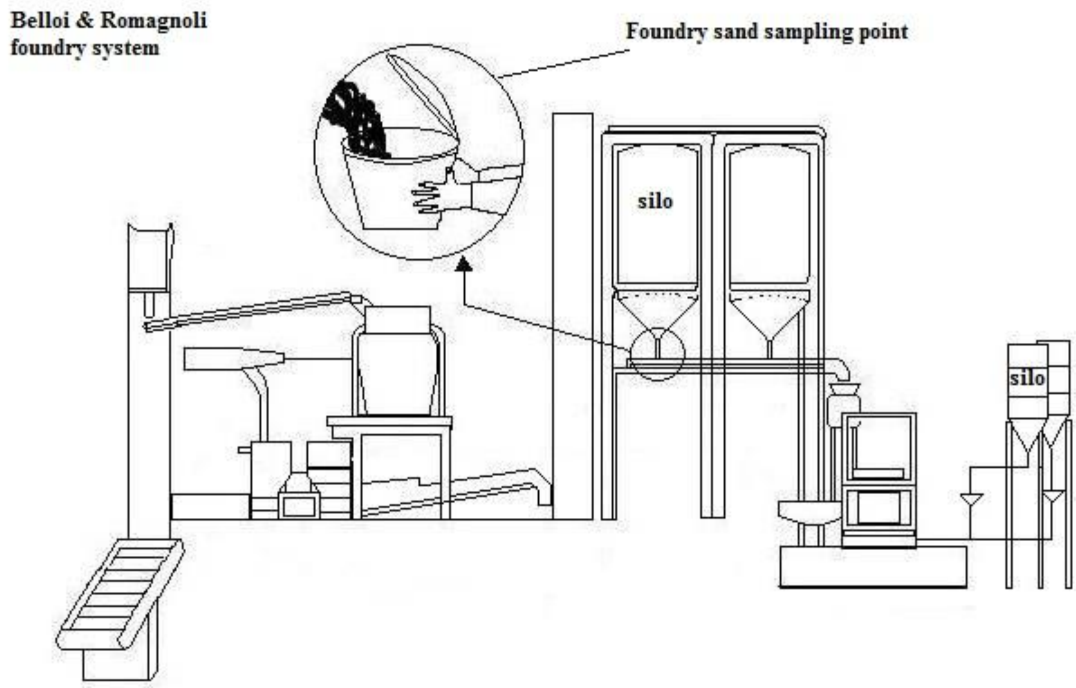

Figure 2: Sampling point in control mechanisms used for quality control system of waste foundry sand.

The control mechanisms imply steps essential to check and control fluctuations in quality of waste foundry sand at least once a year as mentioned in Finnish government degree on waste landfills act (331/2013). Figure 2 illustrates suitable place in foundry system described to collect samples of waste foundry sand. Grains of foundry sand sample collected should be < 4mm. The sampling vessel could be made out of plastic or metallic jar with the dimension that exceeds the width of falling stream. It prevents the particles falling out of the vessel. The sample which is half filled in the jar is preferred to be a minimum of 1 kg. Samples need to be sealed and stored in dry and cool condition before delivering it to the laboratory test. (Orkas,2001).

It is requested to include important information for example, the sampling time, the name of the responsible person, and sampling site. The samples should be sent without any pre-treatment to the laboratory. (Orkas,2001).

1.5.1 Regulating the production process

The process of processing the waste foundry sand to make it reusable in composting and other purposes is subject to the environmental relevant industrial waste management activity (646/2011). The use of the guideline prepared from this proposal does not affect the obligation for composter to hold an environment permit that permits the storage and processing of waste foundry sand.

1.5.2 Criteria for producing the quality waste foundry sand

- The variations in the quality and composition of the waste foundry sand depend on various factors:
  - Variation in the foundry sand composition during casting
  - Variation in composition during number of recycling foundry sand in foundries
  - The influence of the size of casting
  - The effect on composition due to sand handling process (such storage, transfer, cooling). (Orkas, 2001).

Control on above factors improves and brings consistency in quality of the sand.

- Foundries are preferred to be from Finland that uses green sand, furan sand, and alkaline phenolic sand as raw material.
- Foundries are desired to conduct and pass the entire test that was required previously before dumping waste sand in landfill.
- Necessity of different sampling plans on the basis of foundry sand, for example, green sand, furan sand, and alkaline phenolic sand as raw material.

1.5.3 Processed in accordance with approved standards

The proposal appeals foundries to follow the Finnish regulation mentioned earlier in section 1.4, and qualify the approved standard for harmful components on soil shown in Table 1. The foundries are requested to check if samples from different sampling period are under the detection level or standard. If the values of harmful components in the waste foundry sand are under detection level, it is suitable for re-use; otherwise, risk assessment of waste foundry sand is needed. Risk assessment includes change in casting process or changing the factors that affect the quality of waste foundry sand that was mentioned in section 1.5.2 and also consulting the local authorities.

On the basis of the Finnish Environment Institute leaching values, the leaching of the inorganic compounds from the waste foundry sand need to be compared. The different test methods which are described under Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with high content and with particle size below 4 mm (with or without size reduction) (SFS-EN 12457-3) are preferred to conduct.

1.5.4 Dispatch from site for composting and require no further processing

The waste foundry sand that meets the standard can be used for composting and other reuse purposes. It should not need any further processing such as re-screening, leaching test etc. Table 2 given below shows the significant specifications for composting that was performed for Etelä-Suomen Multaravinne Oy in 2003 - 2004 and Table 3 illustrates the significant specification for composting performed for LIFE13 ENV/FI/285 "Foundry sand" project in summer 2015.

Table 2: Specifications used in Etelä-Suomen Multaravinne Oy for composting (Orkas, et al. 2005).

Sand Name	Sand quantity	Bio - waste
Green sand	50% or 80%	20% or 50%
Alkaline phenolic sand	20% or 50%	50% or 80%

Table 3: Specifications used in LIFE13 ENV/FI/000285 for composting (Tapola, S. 2015).

Sand Name	Sand quantity	Pre composting material as sludge and aeration material
Green sand	20% - 30%	70 – 80 %
Alkaline phenolic sand	20% - 30%	70 – 80 %
Furan sand	20% - 30%	70 – 80 %

1.6 Experimental Procedure

According to the provision of Finnish environment Protection act (527/2014) and Waste act (646/2011), the foundries are required to follow Government Decree of Landfills (331/2013) to ensure the recovery of the waste before dumping waste foundry sand to the landfills. The sampling and methods to prepare samples are performed in accordance with standards Tests for general properties of aggregates; Part 1: Methods for sampling and Part 2: Methods for reducing laboratory samples (SFS-EN 932-1 and SFS-EN 932-2) and also draft standard Characterization of waste sampling of waste materials framework for the preparation and application of a sampling plan (prEN 14899). Samples are being taken separately from different production lines and silo and different test method which are described under Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with high content and with particle size below 4 mm (with or without size reduction) (SFS-EN 12457-3) are conducted (VTT, 2000). This shows that Finnish foundries are already performing quality control investigations that investigate and determine harmful substances present in waste foundry sand.

In order to ensure the quality of the system, it is very necessary to define the quality of the waste foundry sand every year. This would be a good practice to monitor the fluctuation in the quality of the waste foundry sand delivered for composting purpose. Initially, quality should be defined at short intervals. If there is less fluctuation in the results during the first year, analysis frequency can be pulled down. The frequency of analysis of the waste foundry sand that would be delivered for composting shall be determined if there is suspect of harmful metals. Otherwise on the basis of Finnish government decree on the waste (179/2012), the surplus foundry sand can be analysed at least once in a year.

2. Discussion and Conclusion

According to the study performed for Etelä-Suomen Multaravinne Oy, no restrictions to use waste foundry sands in the composting process of bio-wastes were found (Orkas, et al. 2005). The results for heavy metals contents were under the standards set by the Finnish Ministry of agriculture and forestry, fertility test was positive and maturity of the composts were stabilized and adequate. The study performed for LIFE13 ENV/FI/285, showed positive result that, waste foundry sand can be cleaned by composting from organic compounds (e.g. PAH, phenol, petroleum hydrocarbons, BTEX) and fluoride that might retain in the surplus foundry sand. The results obtained from various tests were compared to the threshold values set for inert waste landfills regulation and fertilizer regulation and were positive. After discussing with authorities during the experiment, authorized personnel are working to make quality control process easier by adapting Finnish government decree on the waste (179/2012) for analyzing quality of surplus foundry sand once in a year.

Even though experiment performed for LIFE13 ENV/FI/285 “Foundry sand” project is new and not completed yet, its study has demonstrated an innovative composting method for cleaning the surplus foundry sands. The success of composting experiment that was performed in 2003 – 2004 by Etelä-Suomen Multaravinne Oy and by LIFE13 ENV/FI/285 “Foundry sand” project in summer 2015 showed that mixing of surplus foundry sand along with bio-wastes and sludge is profitable situation from both sides (i.e. environment and cost).

This proposal will help to create guideline after discussion with the authorities that would considerably save time and money, reduce the paperwork required for reuse of surplus foundry sand, motivate foundries to improve quality of surplus foundry sand, reduce dependency in natural virgin sand, develop confidence in authorities to give permission and potential users to use the produced compost.

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